THE

ENGINEER'S HANDBOOK

LONDON
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ENGINEER'S HANDBOOK 1

BY

CHARLES S. LOWNDES

ENGINEER, LIVERPOOL

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LONGMAN, GREEN, LONGMAN, AND ROBERTS

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R.M.m.

PREFACE.

The Author has endeavoured in this work, to lay before the young engineer the principles which should guide him in the construction of machinery; and to put together in a concise and intelligible form the necessary rules and tables for his assistance. He has himself used most of these rules habitually for many years, and offers them to the public with every confidence.

The rule for calculating the evaporative power of boilers will be found very useful; by its help any engine may be adapted with a boiler capable of supplying it properly with steam, under whatever conditions it may be worked, with unvarying certainty.

The comparative economical effect of using steam expansively is shown clearly and conclusively in the table of expansions, which is recommended to every engineer's particular attention.

The principles which regulate the speed of steam vessels are as yet somewhat obscure. The Author believes that the article on this subject will not be without value, as at least opening the way, in a practical and intelligible manner, to a more complete exa-

mination of the subject. The rule given has been derived from the results obtained from a number of the fastest and most successful steamers both in this country and in America.

In conclusion, the Author would recommend every young engineer, at his leisure, to scrutinise and investigate every rule carefully, either by going down to the principle of it, or by comparing the results obtained from it, with the best and most successful examples that come before his notice.

LISCARD, NEAR LIVERPOOL.
Oct. 25, 1859.

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AIR PUMP.

CONTENTS at least $\frac{1}{8}$ of that of cylinder, medium about $\frac{1}{6}$ of cylinder, occasionally $\frac{1}{5}$ of cylinder.

Air pump rod usually $\frac{1}{8}$ diameter of pump.

Cylinder diameter	$\times$ ·5	gives	$\frac{1}{8}$	When the stroke is $\frac{1}{2}$ that of the piston.
„	$\times$ ·575	„	$\frac{1}{6}$	
„	$\times$ ·67	„	$\frac{1}{5}$	

For engines working with steam of 4 or 5 lbs. pressure, and for all engines where the pressure is reduced down to that of the atmosphere at the end of the stroke, $\frac{1}{8}$ of the cylinder's content will be found sufficient. For engines using steam of 10 or 12 lbs. throughout, $\frac{1}{6}$ will be a proper size, but for engines working with a pressure of 20 lbs., and carrying their steam throughout, the largest size will be preferable. With these proportions the pump will be capable of lifting fully four times as much water as it will have to do to keep the condensor clear, as will be seen from the examples below.

For instance, take a cylinder 40 ins. diameter, 5 ft. stroke, at 20 revolutions per minute. This cylinder with 5 lbs. steam, $\frac{4}{5}$ full, requires 1 cubic foot water per minute, in the form of steam (see page 42), requiring 23·5 cubic feet water per minute to condense it (see page 59): being $24\frac{1}{2}$ cubic feet of water to be removed by the pump every minute; pump 20 ins. diameter, 2 ft. 6 in. stroke, $\frac{1}{8}$ capacity of cylinder,

of wrought iron, with a shell of brass cast round it. The buckets for large pumps, instead of having one large valve, sometimes have a number of small valves, each about the diameter of the available space between the rod and the edge; when thus arranged, the valves are of a more convenient size, and even though one or two were to get out of order, the pump would still be able to do its work.

Size of valves or passages usually $\frac{1}{4}$ the area of pump.

It may be observed with respect to these, that the speed of the water through them should not be made to exceed 500 ft. per minute; that is, a pump working at a speed of 100 ft. per minute should have a clear area through its valves and bucket of at least $\frac{1}{5}$ the area of the pump, and if working faster than this, the area of passages should be increased proportionably.

Double acting air pumps.—The efficiency of these depends principally on the position of the condensor, the bottom of which should be at least as high as the top of the pump, if it can possibly be so arranged.

BEAMS.

SOLID, RECTANGULAR, AND ROUND: TO FIND THEIR STRENGTH.

Square and rectangular.

$$\frac{(\text{Depth ins.})^2 \times \text{Thickness ins.}}{\text{Length, ft.}} \times \text{Tabular No.} = \text{Breaking}$$

weight, tons.

Round.

$$\frac{(\text{Diameter ins.})^3}{\text{Length in ft.}} \times \text{Tabular No.} = \text{Breaking weight, tons.}$$

Hollow.

$$\frac{(\text{Outside dia. ins.})^3 - (\text{Inside dia. ins.}}{\text{Length, ft.}} \times \text{Tabular No.} =$$

Breaking weight, tons.

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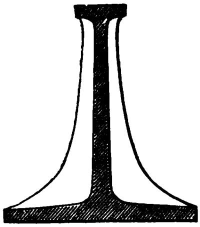
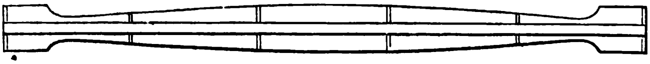
thicker than the top flange, increasing to the bottom to nearly the thickness of the bottom flange; in this way avoiding any sudden variation in the thickness and saving weight; many engineers, however, prefer keeping the same thickness throughout in every part. The vertical brackets for stiffening the girder should not be made straight, but hollowed out something like the sketch, as thus they are much less liable to crack, and all the corners should be well filled in.

Fig. 1.



In most cases it is necessary that the beam should be of uniform depth throughout; it will, however, save weight, without diminishing the strength of the beam, if the width of the bottom flange be reduced very considerably towards the ends; $\frac{1}{2}$ of the width of the middle being quite sufficient; care being taken to maintain a sufficient surface for bearing, if the beam has to be carried on a wall.

Fig. 2.



WROUGHT IRON BEAMS.

I. *Girders.*—The sketch shows a very strong form for this description of girder, when rolled solid. The top flange being condensed and square is in a good form to resist compression; the bottom flange has a wider surface to rest on, and the middle rib is light; an experimental beam of this description 8 ins. deep and 11 feet long requiring 5 tons to break it.

Fig. 3.

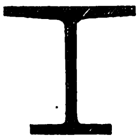
The top flange should have a sectional area $1\frac{1}{2}$ times that of the bottom.

When thus proportioned:

$$\frac{\text{Sec. area top flange, ins.} \times \text{depth ins.}}{\text{Length feet.}} \times 5 = \text{Breaking weight}$$

in tons.

Fig. 4.



This is an inferior shape.

In such a beam the top flange should have an area $1\frac{3}{4}$ that of the bottom flange.

When thus proportioned:

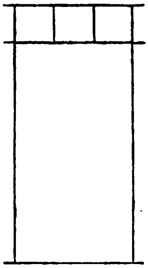
$$\frac{\text{Sec. area top flange ins.} \times \text{depth ins.}}{\text{Length feet.}} \times 4 =$$

Breaking weight, tons.

Beams of the above forms, made of plates and of L iron, are of equal strength with the above; care being taken to make the bottom flange of double plates, with joint plates over the butts, allowing a little extra area in the bottom to compensate for the rivet holes, though this is not necessary if they are rivetted up by steam.

WROUGHT IRON BEAMS.

Fig. 5.



Hollow Girders.—The sketch represents the form for hollow girders combining the greatest strength with the least weight, the top being in the best form for resisting compression.

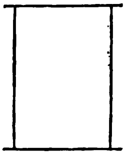
The proportion of the bottom sectional area to that of the top should be as 11 to 12, or $\frac{4}{5}$; and the sides should be well stiffened with angle iron, to keep them from buckling; the sectional area of the top and bottom may be reduced at the extremities to $\frac{1}{3}$ of the area at the middle, without diminishing the strength of the beam.

When thus proportioned:

$$\frac{\text{Section. area top, ins.} \times \text{depth ins.}}{\text{Length feet.}} \times 5 = \text{Breaking weight, tons.}$$

An experimental beam of this form, 75 feet long between supports, 4′ 6″ deep, with 6 cells at the top, about 6″ square each, with a sectional area 24 sq. ins., the sides stiffened with 1½ L irons, 2 feet apart, required 86 tons to break it.

Fig. 6.



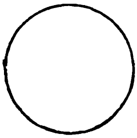
In the plain hollow girder the top should have a sectional area 1¾ that of the bottom.

Thus proportioned:

$$\frac{\text{Sec. area top, ins.} \times \text{depth ins.}}{\text{Length feet.}} \times 4 = \text{Breaking weight, tons.}$$

To find the strength of a round girder.

Fig. 7.



$$\frac{\text{Sec. area, ins.} \times \text{dia. ins.}}{\text{Length feet.}} = \text{Breaking weight, tons.}$$

To find the strength of any beam.

If the top flange is the weakest, find the compressive breaking strain in tons per square inch due to its shape, thickness, and length. (See COLUMNS.)

If the bottom is the weakest, find the tensional breaking strain of the material in tons per square inch.

Then,

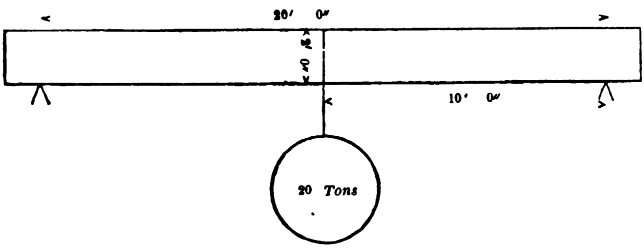
$$\frac{\text{Sec. area ins. of weakest flange} \times \text{breaking strain, tons pr. inch} \times \text{depth of beam ft.} \times 4}{\text{Length between supports, feet.}}$$
$$= \text{Breaking weight, tons.}$$

This rule will be found useful, either to confirm the results obtained from the previous rules, or to find the strength of any beams of irregular shape not included in them.

The mode of ascertaining the compression and tension on the top and bottom flanges of beams is sufficiently simple.

Take the case of a beam, 20 feet long, 2 feet deep, with a weight of 20 tons on the middle; the force counteracting this weight will be 10 tons on each end; the force of com-

Fig. 8.



pression at the top in the middle of the beam, and that of tension at the bottom, taking the central weight as the fulcrum, will be just in proportion to the leverage; in this case, as 10 to 2, or 5 to 1. The force of 10 tons applied to the end will thus result in a force of 50 tons of compression and tension on the flanges in the middle of the beam. Or in a simple form,

$$\frac{\text{Weight, tons} \times \text{length, feet}}{\text{Depth, feet} \times 4} = \text{Strain on top and bottom flanges, tons.}$$

The ultimate compressive strength of boiler plate iron may be taken at 16 tons per square inch, the tensile strength at 20 tons per square inch; and this is the reason why, in all wrought iron beams, the top requires to be the strongest.

But as in cast iron the compressive strength is about 48 tons, while the tensile strength is only about 7 tons per square inch, the bottom flange in cast iron girders requires to be much the strongest.

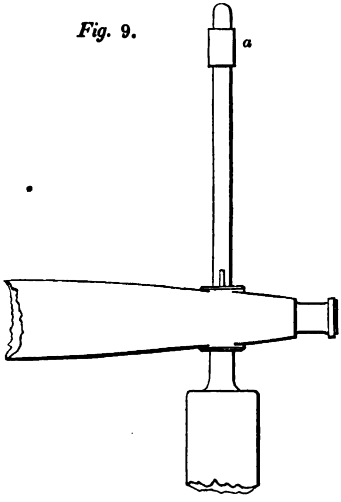
The fullest information on this subject, and the experiments in detail, will be found in Mr. Eaton Hodgkinson's

experiments on the strength of cast-iron beams, and in Mr. Edwin Clark's work on the Britannia and Conway tubular bridges.

BILGE PUMP.

Usually same capacity as the feed pump; if, however, the engine is very small in proportion to the vessel, it should be made larger than this. Principal points to be observed in construction and arrangement: the pump should be so arranged that it may be connected or disconnected without stopping the engine; various ways of effecting this will occur to every engineer. A simple and safe way for beam engines is shown in the sketch.

Fig. 9.



The pump rod passes through the air pump crosshead, having a good shoulder below; the pump is put in gear by driving in the cutter when the crosshead is at the bottom of its stroke. When in gear the rod works through the guide *a*, when out of gear the rod itself forms a guide for the crosshead. The cutter should have a cross-pin for security, and should be hung up clear of the engine when not in use.

The valve box should be fixed in a convenient place clear of the engine, and some height above the ship's floor, so that it may be examined, and cleared if necessary, without

stopping the engine; and so that it may be accessible even though there should be a good deal of water in the vessel.

The discharge pipe should be connected to the ship's side close under the deck, or, at all events, considerably above the water line; this is an important point, as it may happen that both valves will get choked, and if the discharge is below the water surface there is nothing to prevent the water from flowing from the sea into the hold, besides which the valve box cannot be overhauled without a great deal of difficulty.

The suction pipe should have a large copper rose with small holes in a convenient and attainable place for keeping it clear. The pump should be fitted with a pet cock.

Plunger and valve seats of gun metal.

Valves of gun metal or india-rubber.

Discharge pipe of copper.

Suction pipe usually lead, but copper is preferable.

BOILERS.

To find the horse power approximately.

$$\text{Land boiler} \frac{(\text{Dia. ft.} + \text{dia. inter. flue}) \times \text{length ft.})}{6} = \text{H.P.}$$

$$\text{Marine boiler} \frac{\text{Rough cubic contents}}{16} = \text{H.P.}$$

To find the evaporating power of any boiler.

Find the effective heating surface in square feet of the furnace and flues separately.

$$\left.\begin{array}{l}\text{All top horizontal surface} \\ \tfrac{1}{2}\ \text{vertical surface} \\ 1\tfrac{1}{4}\ \text{the diam. of tubes or round flues} \\ 1\tfrac{1}{8}\ \text{to}\ 1\tfrac{1}{6}\ \text{the horizontal surface of moderate} \\ \quad\text{curves, as the bottom of waggon boilers}\end{array}\right\}\ \begin{array}{l}\text{being taken} \\ \text{as effective} \\ \text{surface.}\end{array}$$

Then $\frac{\text{Furnace eff. surface}}{3}+\frac{\text{1st flue eff. surface}}{3\sqrt{\text{prop. of flue + furnace to fire}}}$

$+\frac{\text{2nd flue eff. surface}}{3\sqrt{\text{prop. of total flue + furnace to fire}}}$

= Water evaporated in cubic feet per hour from cold fresh water, when burning the following quantities of coal per square foot of grate per hour.

10 lbs. best Welsh coal.
12 „ average do.
13 „ good Newcastle, Lancashire, and Yorkshire.
15 lbs. Scotch coal.
$11\frac{1}{2}$ „ patent fuel.
10 „ coke.

The evaporation when burning a less or greater quantity with the natural draught being nearly in direct proportion to the quantity of coal consumed, up to 15 lbs. best Welsh coal per foot per hour and up to 30 lbs. of the fast burning coals.

The following table will assist in finding the divisors: —

Total to Fire.		Divisor.	Total to Fire.		Divisor.	Total to Fire.		Divisor.
1·1	$\sqrt{}\times 3$	3·15	5·5	$\sqrt{}\times 3\cdot$	7·02	16	$\sqrt{}\times 3\cdot$	12·
1·2	—	3·27	6	—	7·38	17	—	12·36
1·3	—	3·42	6·5	—	7·65	18	—	12·72
1·4	—	3·54	7	—	7·92	19	—	13·08
1·5	—	3·675	7·5	—	8·16	20	—	13·41
1·6	—	3·795	8	—	8·49	21	—	13·74
1·7	—	3·9	8·5	—	8·7	22	—	14·07
1·8	—	4·02	9	—	9	23	—	14·4
1·9	—	4·12	9·5	—	9·24	24	—	14·7
2	—	4·2	10	—	9·48	25	—	15·
2·5	—	4·74	10·5	—	9·72	26	—	15·3
3	—	5·19	11	—	9·96	27	—	15·6
3·5	—	5·61	12	—	10·38	28	—	15·9
4	—	6	13	—	10·8	29	—	16·2
4·5	—	6·36	14	—	11·22	30	—	16·43
5	—	6·72	15	—	11·61			

In marine boilers there must be deducted from the final result, $\frac{1}{8}$ for the loss in blowing off, if with ordinary blowoff cocks, $\frac{1}{10}$ if with surface blowoff cocks.

The close approximation this mode of calculating will give to the actual evaporation, will be seen from the two following well-known boilers: —

Waggon Boiler, Albion Mills.

$$\left.\begin{array}{r} 16'\ 0''\ \text{long} \\ 6'\ 0''\ \text{wide} \\ 8'\ 6''\ \text{high} \end{array}\right\} \begin{array}{l} \text{Flue through boiler } 4'\ 3''\ \text{diam.} \\ \text{Furnace } 6'\ 0''\ \text{wide} \times 4'\ 0''\ \text{long.} \end{array}$$

Fire surface, 24 square feet.

	Divisor.	Eff. ft.		Cub. ft.	
Furnace	$\frac{1}{3}$	27	=	9	evaporated per hour.
Under boiler	$\frac{1}{6\cdot36}$	81	=	12·7	"
Flue	$\frac{1}{8\cdot5}$	85	=	10	"
Round	$\frac{1}{10}$	100	=	10	"
				41·7	

That is 41·7 cubic feet of water evaporated per hour while burning 13 lbs. Newcastle coal per foot per hour, equal to 52·7 cubic feet while burning 16·5 lbs. per foot.

Actual evaporation 55·6 cubic feet per hour, from 100° burning 16½ lbs. Newcastle coal per foot, per hour.

Explanation.—Furnace, effective feet divided by 3 gives 9 cubic ft. Under the boiler $\frac{81 \text{ ft} + 27 \text{ ft. furnace}}{24 \text{ ft. fire}}$ gives 4·5 as the proportion of absorbing surface to fire, and $3\sqrt{4\cdot5}$ gives 6·36 as divisor for the surface under the boiler.

Flue $\frac{85 \text{ ft.} + 108 \text{ ft. previous surface}}{24 \text{ ft. fire}} = 8$ and $3\sqrt{8} = 8\cdot5$ as divisor for this. The divisor for the surface round the boiler being found in exactly the same way.

Cornish Boiler.

36′ 0″ long 6′ 0″ diam.	Tube through boiler 4′ 0″ diar. Furnace 4′ 0″ wide, and 6′ 0″ long.

Fire, 24 square feet.

	Divisor.	Eff. Surf.		Cub. ft.	
Furnace	$\frac{1}{3}$	30	=	10	evap. per hour.
Remainder of flue	$\frac{1}{8}$	157	=	19·6	"
Round	$\frac{1}{11\cdot6}$	172	=	15·7	"
Under	$\frac{1}{14}$	172	=	12·	"
				57·3	

57·3 cubic feet while burning 12 lbs. Welsh coal per square foot per hour; equal to 13·5 cubic feet while burning 2·83 lbs. per foot.

Actual evaporation 11·8 cubic feet from 100° while burning 2·83 lbs. Welsh coal per foot, per hour.

The cause of the deficiency in this case in the actual evaporation below the calculated will appear pretty clearly in treating of the economy of boilers.

For Boilers with an artificial draught, see LOCOMOTIVE.

To ascertain the actual evaporation of any boiler.

After the boiler has been at work a little time, and is doing its best, feed up the boiler to the top of the glass, and then shut the feed completely off: weigh all the coal put on after this time, and notice the time occupied in reducing the water from the top of the glass to the bottom. From these data the effective evaporating power of the boiler can be ascertained very closely, care being taken to leave as much fire at the termination as at the commencement.

To find the evaporation from the above data.

$$\frac{\text{Water surface, sq. ft.} \times \text{evaporation ins.} \times 5}{\text{Minutes occupied in evaporation}} = \text{Evaporation of}$$

water, cubic feet, per hour.

To find the economical evaporation.

$$\frac{\text{Evaporation per hour, cubic ft.} \times 62{\cdot}5}{\text{coal consumed per hour, lbs.}} = \text{Water evaporated}$$
lbs. per lb. of coal.

ECONOMY OF BOILERS.

The comparative economical results, derived from boilers with different proportions of heating surface, and with different rates of combustion, are shown in the following experiments made by the Admiralty on a marine boiler at Woolwich of 80 H.P. the size of the furnace being varied, and the experiments being made with the best Welsh coal, hand picked.

Tube surface, 330 effective square feet.

	Fire Grate.	Total effective surface to Fire.	Coal burnt per hour per sq. ft. grate.	Evaporation per hour cubic feet water.	Evaporation from 100° per lb. coal.
1	52 sq. ft.	9 to 1	7 lbs.	70	9·3 lbs.
2	„ „	„ „	15 „	110	8·8 „
3	34 sq. ft.	13 to 1	9 lbs.	55	11·23 lbs.
4	„ „	„ „	12 „	68	10·4 „
5	26 sq. ft.	16·7 to 1	$10\frac{1}{2}$ lbs.	56	12·8 lbs.
6	„ „	„ „	$17\frac{1}{2}$ „	77	10·88 „

In the two boilers previously calculated, if the evaporation be reduced to lbs. water, per lb. best Welsh coal, the result will be : —

	Total effective surface to Fire.	Evaporation from 100° per lb. coal.
Albion Mills . . .	13 to 1	11·4 lbs.
Cornish . . .	22 to 1	13·3 „

The Albion Mills boiler giving an economical result fully

higher than the Woolwich boiler, with the same proportion of absorbing surface to fire grate.

The Cornish boiler, though with considerably more surface, and working at an exceedingly slow rate of combustion, very slightly exceeding in economical effect the Woolwich boiler with a quick combustion; and even this advantage being possibly derived from the different quality of coal the boiler is calculated as using.

It would seem nearly conclusive from these examples that there is no advantage in point of economy in having a larger proportion of total effective surface to the fire than 16 to 1. It would also seem that very great economy can be obtainable with a fair rate of combustion, and that the excessively slow combustion practised in Cornwall is not a requisite.

PROPORTIONS OF BOILERS.

	Marine.	Land.	
Fire grate	·5 to ·8	·7 to 1	sq. ft. per nom. H.P.
Total heating surface	15 „ 25	15 „ 35	

A very good proportion for both purposes will be found.—

Fire grate $\frac{3}{4}$ sq. ft. per H.P. or per cubic foot to be evaporated per hour; and Total effective heating surface varying from 9 to 16 square feet for every foot of fire grate; 9 as a minimum, when the boiler is required to be as compact as possible; 16 as a maximum, when the greatest economy of fuel is desired.

In the case, however, of engines working much above their nominal power, of engines working expansively, and of most marine engines, the proper plan is to ascertain what steam is really required by the engine, and what evaporation of water will be required to produce that steam (see Engines, page 42), and then to arrange the proportions of the boiler, so as to give the required result when calculated over by the previous rule for ascertaining the evaporative power *of boilers.*

Section through tubes $\frac{1}{4}$ to $\frac{1}{4}$ of fire grate.
„ chimney $\frac{1}{7}$ „ $\frac{1}{8}$ „

The smaller proportion is sufficient when a moderate rate of combustion is intended, say 13 or 14 lbs. per foot per hour, of Newcastle coal. The larger size will give a quicker draught, and will enable the boiler to burn without forcing much more coal, and to evaporate an increased quantity of water nearly in proportion to the coal consumed, provided the chimney be not deficient in height. (See CHIMNEY, page 21.)

STRENGTH OF BOILERS.

To find the pressure that a circular boiler may be safely loaded with, if made of the best Staffordshire plates.

$$\frac{11200}{\text{Dia. ins.}} \times \text{thickness of shell} = \text{Pressure in lbs. per sq. in.}$$

Thus loaded, the strain on the boiler is equal to about $\frac{1}{8}$ the breaking strain.

Or simply, if the shell is of $\frac{3}{8}$ plates, best Staffordshire,

$$\frac{350}{\text{Dia. feet.}} = \text{Pressure in lbs. per sq. in. it may be safely}$$
loaded with.

For every $\frac{1}{16}$ additional thickness up to $\frac{1}{2}$ thick, add $\frac{1}{6}$.
For best Yorkshire plates „ $\frac{1}{5}$.
For double rivetted longitudinal seams „ $\frac{1}{7}$.

Best Staffordshire plates may be taken as carrying	20 tons per sq. in.
Best Yorkshire plates . . .	24 „ „

To find the strain on the plates with a given pressure in a boiler.

$$\frac{\text{Dia. ins.} \times \text{pressure lbs. per in.}}{\text{Thickness plates} \times 2.} = \text{Strain on plates per sq. in.}$$

A seam single rivetted will bear $\frac{2}{3}$ } of the weight that will
„ double rivetted „ $\frac{4}{5}$ } break the solid plate,
provided the rivets be properly proportioned and spaced.

In large circular boilers with internal tubes, especially when the boiler is very long, the flue tubes require to be carefully strengthened, if intended to carry the same strain as the shell is capable of. In some experiments that Mr. Fairbairn made on a boiler 7′ 0″ diameter, 30 ft. long, with 2 flues 3′ 0″ diameter; one of the flues collapsed with 100 lbs. per sq. in., while the shell would require 300 lbs. per sq. in. to burst it.

Mr. Fairbairn also found that a tube 3′ 6″ diameter, 10′ 0″ long, required 300 lbs. per sq. in. to collapse it; and he recommends rigid rings, at intervals of 10 ft., to be used for stiffening the internal flues, in those cases where the length and the pressure make it necessary.

RIVETS.

The following will be found good proportions: —

Dia. = twice thickness of plates Distance centre to centre = 3 times dia.	Single rivetting.
Dia. = $1\frac{1}{2}$ times thickness of plate Centre to centre = 4 times dia.	Double rivetting.

FORM OF BOILERS.

The common egg ended boiler is a good form for small sized boilers.

Diameter, 2′ 6″ to 3′ 6″. Length 5 to 8 times diameter, and sometimes even longer.

The best way of setting, if the boiler is long enough, is with a straight flue from the fire all under the boiler, bricked an equal distance from the boiler all along, to make the heat spread properly; the length of fire grate being made about $\frac{1}{8}$ the length of the boiler, and the boiler being carried either on a thin central wall or on brackets.

The Cornish boiler is a very good form for sizes from 4′ 0″ to 6′ 0″ diameter, either egg ended, or flat ended; length 4 to 5 times diameter, with a fire flue inside. The simplest way of setting is with a central wall, the flue round the outside dipping under the front to return.

It is a good plan in making this description of boiler to put the angle iron for the front on the outside; this will enable the fire flue to be 3 ins. larger in diameter at the furnace end than it would otherwise be, which, especially in small boilers, is a considerable advantage for the furnace. Boilers above 6′ 0″ may have 2 flues inside; length of boiler 3 to 4 times diameter.

In setting land boilers, of whatever description or form, it will be found very beneficial to set the brickwork as close to the boiler all along as possible, leaving a proper sectional area to the flue; the effect of this is to keep the flame or heat closely and equally in contact with the surface of the boiler, which also gets the benefit of the heat radiating from the brickwork; this tells when the furnace is fresh coaled, and boilers set in this way always make steam steadily.

For marine boilers of the ordinary description, it is an improvement to have dry water bottoms, and an outside

smokebox; the dry water bottoms are a decided improvement, saving both weight, cost, and fuel; and as the old water bottoms were always exposed more or less to the damp and steam from the bilge, they nearly always gave out before the rest of the shell of the boiler, and were very troublesome to repair.

The smoke box outside is also an improvement, provided that the boiler has sufficient surface in the tubes to absorb the heat from the fire properly, otherwise it becomes very hot. If, however, the chimney take up is made to pass through the steam space or steam chest, particular care should be taken to carry it up as straight as possible after it is once clear of the water, as this part of the boiler is exceedingly liable to be burned away; it is also liable to salt up very fast in the thin space between the boiler front and the take up, and it is a good plan to have a cock on the front, and to blow off the saturated water regularly from this part of the boiler.

It is also an improvement to have the crowns of the furnaces semicircular, as they then require no stays above the fire, and are much less liable to buckle.

FURNACE.

The length of furnace, in a round fire flue, should not much exceed twice the diameter of the flue, if a quick draught is desired; otherwise there will not be sufficient area over the bridge, nor at the front for admission of air.

And 8 ft. is the outside length advisable in any case.

2′ 6″ to 2′ 10″ from the floor is the most convenient height for firing.

Bars, $\frac{1}{2}$ to $\frac{3}{4}$ thick — $\frac{3}{8}$ to $\frac{5}{8}$ spaces, depending on the quality of the coal.

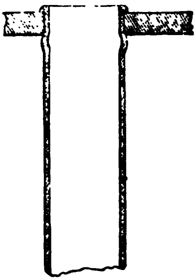
Working height of water over flues 8″ to 10″; 4″ minimum working height in any case.

10½″ clear must be left between bottom of tubes and crown of furnaces in marine boilers, in order to allow room for scraping and scaling the furnace tops and sides.

TUBING.

In tubing marine boilers with iron tubes, a good plan is, after putting the tube into its place, first to hammer out a slight swell behind the tube plate with a ball end hammer, then rivet and turn over and finish with a good moulding tool; this is a simple and secure way, and every tube acts as a stay both ways.

Fig. 10.



For brass tubes for locomotives, drift up mandrels at both ends at the same time, take out mandrels and rivet over, then put in again and finish with moulding tool.

CHIMNEY.

The proper area under any circumstances may be found by Watt's rule.

$$\frac{\text{lbs. coal burned per hour} \times 12}{\sqrt{\text{height, feet.}}} = \text{Area, square inches.}$$

A common proportion for marines with 2 engines, and locomotives, is to make the chimney the same diameter as the cylinder.

BRICK CHIMNEY.

Each side of a chimney with a square base should be 1 ft. wide at least for every 10 ft. in height.

COAL.

The comparative evaporating power of different coals may be stated as follows: —

	Lbs. water evaporated from 212° by 1 lb. coal.		Space occupied as stowed in Bunkers. Cub. ft. per ton.	
		Average.		Average.
Best Welsh, Ebb Vale, Duffryn, and Merthyr	10 to 10·2	10	42	42
Average Welsh	7·5 — 10	9	33 to 45	39
Patent Fuel	8·5 — 10·3	9	32 — 36	34
Lancashire	7·2 — 8·8	8	40 — 46	43
Newcastle	6·8 — 9·3	8	40 — 47	43½
Scotch	7 — 8·5	7·7	40 — 50	45
Derbyshire	. .	7·3		
Dry wood	. .	4		

The above table does not represent the highest evaporating power of the different coals, but the comparative evaporating power as ascertained in the experimental boiler at Woolwich.

12¾ lbs. water have been evaporated from 100° per lb. best Welsh coal. Woolwich experiments.

12¼ lbs. water have been evaporated from 100° per lb. best Newcastle, with smoke burning apparatus. Newcastle experiments.

These being the highest results recorded, and both obtained from boilers having about 16 sq. ft. efficient heating surface to 1 sq. ft. of fire grate.

The space allowed in the Navy for stowage is 48 cubic ft. per ton.

BOLT—CUTTER.

A strain of 4000 lbs. on whole area is equal to about $2\frac{1}{2}$ tons per inch on actual area at threads; 6000 on whole area = about 4 tons actual area at threads.

The first is a good proportion to use for joints, &c. which can allow of no perceptible stretching; the last for pedestals, &c. if lightness is particularly requisite.

In long bolts or rods intended to carry a considerable tensile strain, both ends should be swelled out to $1\frac{1}{4}$ times the diameter of the body of the rod, in order to compensate for the loss caused by the cutter hole at the one end and the threads for the nut at the other. And the cutter to have equal strength with the bolts should have the following proportions:—

Depth	=	$1\frac{1}{4}$ dia. of largest part of rod.
Thickness	=	·22 " " "

Cutters for engine work are usually made as follows:—

Depth	=	dia. of rod or bolt.
Thickness	=	$\frac{1}{4}$ do.
Taper		$\frac{1}{2}$ per foot, is a good proportion.

A good mode of securing the cutters for those parts of marine engines, principally the crank end of the connecting rod, which occasionally require to be adjusted while the engine is in motion, is sketched herewith; the screw being put upon the gib instead of the cutter, the cutter can be driven back or forwards without fear of injury; and the nuts being made with projections can be loosened or tightened with a hammer with the greatest facility.

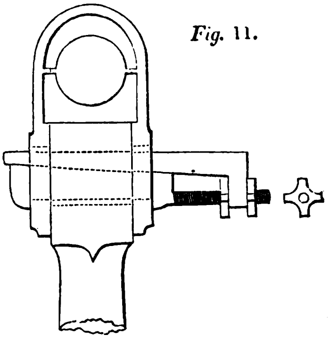


Fig. 11.

BORING AND TURNING.

The best speed for boring cast iron is about $7\frac{3}{4}$ feet per minute.

For drilling about 10 or 11 feet per minute is a good speed for the circumference of the tool. For a 1″ drill 40 revs. = 11 ft. per minute, other sizes in proportion.

For turning, the proper speed for the circumference is about 15 feet per minute.

BRASS.

Compositions of Brass.

	Copper.	Tin.	Zinc.
Watch-maker's brass . . .	1 part	—	2 parts
German brass . . .	1 ,,	—	1 ,,
Yellow brass . . .	2 ,,	—	1 ,,
Speculum metal . . .	2 ,,	1 part	—
Bell metal	3 ,,	1 ,,	—
Light castings and small bearings .	4 ,,	1 ,,	$\frac{1}{4}$,,
Ditto a little harder . .	4 ,,	1 ,,	$\frac{1}{2}$,,
Heavy castings . . .	6 to 7	1 ,,	1 ,,
Gun metal	9 ,,	1 ,,	—

The addition of a little lead makes the metal more easily wrought, and is advantageous when the work is not intended for exposure to heat.

BRASS CASTING.

As it is often useful to engineers, especially abroad, to be able to cast brass, a slight description of the process may not be out of place. The ordinary furnace used is of very simple construction, as may be seen from the sketch annexed.

a is the body of the furnace.

b is the chimney with an area at least $\frac{1}{4}$ that of the fire

Fig. 12.

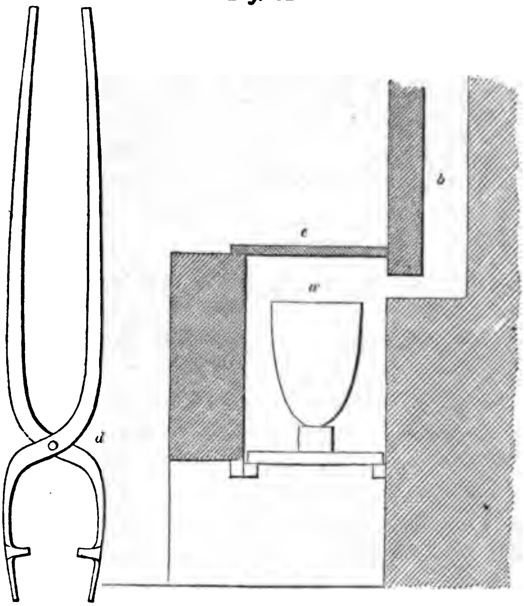
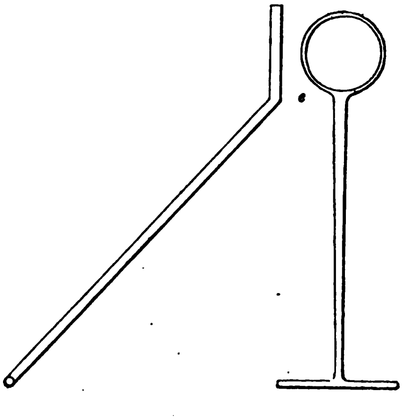


Fig. 13.



grate; it should be fitted with a damper to regulate the draught.

c is the covering plate.

d tongs for lifting the pot off the fire.

e pouring tongs.

The front bearer for carrying the bars should not be built in as a fixture, but should have a small recess provided for it to slide forward in, so as to let the front end of the bars drop down when required.

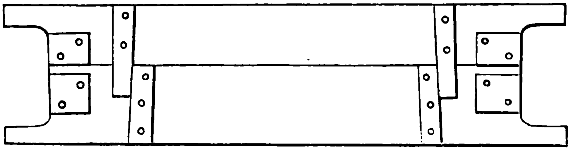
After lighting the fire, put the pot intended for use bottom upwards over it, so as to warm gradually through. As soon as the fire is burned well through, put the pot into its place, resting the bottom on a fire brick to keep it off the bars, and filling round with lumps of coke to steady it; then put in the copper, either blocks cut up into pieces of convenient size, or if this is not to be had, sheet copper doubled up; as the metal sinks down add more copper or old brass till the pot is nearly full of melted metal; now add the tin, and when this is melted and mixed, put in a piece or two of zinc; if this begins to flare add the rest of the zinc in, stir it well in, lift the pot off at once, skim the rubbish off the top, and pour into the mould. If, however, it does not flare up, put a little coal on to excite the fire, and cover over till it comes to a proper heat. As soon as the zinc begins to flare, add in the rest, and take the pot off the fire. If old brass alone is melted down no tin is required, but a small quantity of zinc. If part copper and part brass, add tin and zinc in proportion to the new copper, with a little extra zinc for the brass.

As soon as the boxes are run, it is the usual custom to open them at once, and to sprinkle the castings with water from the rose of a watering can, this has the effect of making them softer than they would otherwise be; the boxes are then emptied, and fresh moulds made while fresh metal is being melted.

When the casting is completed, draw the bearer forward, and let the bars all drop, so that the furnace can be effectually cleared from the clinkers, and put the pot among the ashes to cool gradually.

The moulding boxes may be of hard wood, well secured at the corners, either by dovetailing or by strong nails and iron corner plates, with guides to keep the boxes fair with one another. A few cross bars in the top box help to carry the sand.

Fig. 14.



Fresh green sand, the same as used for iron founding, mixed with a small quantity of coal dust, about $\frac{1}{12}$ part, should be sifted over the patterns on all sides to the thickness of about an inch, the box then filled up with old sand, and properly rammed up, and well pricked to let the air and gas escape, then remove the patterns, and dust over the mould with a little charcoal powder from a bag, or with a little flour, cover over the box again, and the mould is ready for pouring.

For long articles, spindles, bars, &c. make a good airhole at the opposite end from where the metal is poured, incline the box slightly, and pour the metal at the lower end; for flat, thin and straggling articles it is necessary to have two or more pouring holes, and to fill them all at the same time.

The pots generally used are the Stourbridge clay pots, and black lead pots, both kinds being made of various sizes up to 60 lbs.; the former are less durable, but much cheaper

than the latter, they require to be carefully hardened by gradual exposure to the fire.

Clay pots are made of 2 parts raw Stourbridge clay to 1 of gas coke pulverised; well mixed up together with water, dried gently, and slightly baked in a kiln.

Black lead pots of 2 parts graphite, and 1 of fireclay, mixed with water, baked slightly in a kiln, but not completely until required for use.

The pots are made on a wood mould, the shape and size of the inside of the pot, the clay being plastered round it to the thickness desired.

BRICKWORK.

Bricks. Ordinary size, $8\frac{3}{4}'' \times 4\frac{1}{4}'' \times 2\frac{1}{2}''$. Weight, 4 lbs. 15 oz.

272 superficial feet, or 306 cubic feet make 1 rod of reduced brickwork of the standard of $1\frac{1}{2}$ brick thick.

1 rod of brickwork weighs 13 tons.
1 cubic foot „ „ 125 lbs.
18 cubic foot = 1 ton.

To find the number of bricks in any piece of work.

Area of wall in square feet × No. of bricks in thickness × 11 = No. of bricks.

For instance; To find the number of bricks in 1 rod reduced brickwork, $1\frac{1}{2}$ brick thick.

1 rod = 272 superficial feet.

$272 \times 1\frac{1}{2} \times 11 = 4488$ the number required.

or, Cubic contents × 14·7 = Number of bricks.

CASE HARDENING.

Put the articles requiring to be hardened, after being finished but not polished, into an iron box in layers with animal carbon, that is, horns, hoofs, skins, or leather, partly burned so as to be capable of being reduced to powder, taking care that every part of the iron is completely surrounded; make the box tight with a lute of sand and clay in equal parts, put the whole into the fire, and keep it at a light red heat for half an hour to two hours, according to the depth of hardened surface required, then empty the contents of the box into water, care being taken that any articles liable to buckle be put in separately and carefully, end in first.

Cast iron may be case hardened as follows : —

Bring to a red heat, and roll it in a mixture of powdered prussiate of potash, saltpetre and sal-ammoniac in equal parts, then plunge it into a bath containing 2 oz. prussiate of potash, and 4 oz. sal-ammoniac per gallon of water.

CENTRIFUGAL FORCE.

$$\frac{(\text{Revolutions per min.})^2 \times \text{dia. in ft.} \times \text{weight}}{5870} = \text{Centri-}$$

fugal force in terms of weight.

COCKS.

3 inches per ft. is a very good taper for the plug.

Bottom diam. of plug, $1\frac{1}{4}$ times diam. of hole.

Square of plug, $\frac{1}{2}$ diam. of hole ; height the same.

Length of handle, 6 times diam. of hole.

For marines and engine work, the principal cocks should always have solid bottoms, and be fitted at the top with a gland packed with hemp or india-rubber.

COLD WATER PUMP.

Usually $\frac{1}{4}$ of cylinder diam. when the stroke is $\frac{1}{2}$ that of piston.
$\frac{1}{3}$ „ „ $\frac{1}{4}$ „

To find the proper size, under any circumstances, capable of supplying twice the quantity ordinarily used for injection.

$$\frac{\text{Cub. ft. water per hour used in cylinder in form of steam}}{\text{Stroke of pump, ft.} \times \text{strokes per minute}} =$$

Area of pump in sq. ft.

For Rule, see page 42.

SOLID COLUMNS

Fail by crushing with length under	5 diameters.
Principally by crushing from	5 to 15 „
Partly by crushing, partly by bending, from	15 to 25 „
Altogether by bending above	25 „

		Per square inch.
Cast iron of average quality	is crushed with	- 49 tons
Wrought iron	„ „ „	- 16
„	is permanently injured with	- 12
Oak „	is crushed with -	- 4
Deal „	„ „ „ -	- 2

The comparative strength of different columns, of different lengths, will be seen very clearly from the following table derived from experiments by Mr. Hodgkinson :—

Wrought Iron Bars.		Proportion of Length to Thickness.	Gave way with
Square	Length.		
ins.	ft. ins.		
1 × 1	7½	7½ to 1	21·7 tons per sq. inch
"	1 3	15 to 1	15·4 "
"	2 6	30 to 1	11·3 "
"	5 0	60 to 1	7·5 "
"	7 6	90 to 1	4·3 "
½ × ½	5 0	120 to 1	2·5 "
"	7 6	180 to 1	1· "

To find the strength of any wrought iron column with square ends.

Area of column sq. ins. × tons per in. corresponding to proportion of length, as per table above = Breaking weight, tons.

If the ends are rounded, divide the final result by 3 to find the breaking weight.

In columns of oblong section, the narrowest side must always be taken in calculating the proportion of height to width.

To find the strength of round columns exceeding 25 diameters in length. Mr. Hodgkinson's rule.

$$\frac{(\text{Diameter, ins.})^{3\cdot6}}{(\text{Length, ft.})^{1\cdot7}} \times \text{Tabular No.} = \text{Breaking weight, tons.}$$

	Square Ends.	Rounded or Moveable Ends.
Wrought iron . .	77	26
Cast iron . . .	44	15
Dantzic oak . .	4·5	1·7
Red deal . . .	3·3	1·2

A column should not be loaded with more than ⅓ of the breaking weight in any case, and as a general rule, not with more than ¼; for purposes of machinery not with more than ⅙ to $\frac{1}{10}$, according to circumstances.

TABLES OF POWERS FOR THE DIAMETERS AND LENGTHS OF COLUMNS.

Diameter.	3·6 Power.	Diameter.	3·6 Power.
1″	1·	7″	1102·4
¼	2·23	¼	1251·
½	4·3	½	1413·3
¾	7·5	¾	1590·3
2	12·1	8	1782·9
¼	18·5	¼	1991·7
½	27·	½	2217·7
¾	38·16	¾	2461·7
3	52·2	9	2724·4
¼	69·63	¼	3006·85
½	90·9	½	3309·8
¾	116·55	¾	3634·3
4	147·	10	3981·07
¼	182·9	¼	4351·2
½	224·68	½	4745 5
¾	272·96	¾	5165·
5	328·3	11	5610·7
¼	391·36	¼	6083·4
½	462·71	½	6584·3
¾	543·01	¾	7114·4
6	632·91	12	7674·5
¼	733·11		
½	844·28		
	967·15		

Length.	1·7 Power.
1	1·
2	3·25
3	6·47
4	10·556
5	15·426
6	21·031
7	27·332
8	34·297
9	41·9
10	50·119
11	58·934
12	68·329
13	78·289
14	88·8
15	99·85
16	111·43
17	123·53
18	136·13
19	149·24
20	162 84
21	176·92
22	191·48
23	206·51
24	222·

HOLLOW COLUMNS.

Hollow columns fail principally by crushing, provided the length does not exceed 25 diameters; indeed, the length does not appear to affect the strength much till it exceeds 50 diameters.

The comparative strength of different forms and of different thicknesses will appear so distinctly from the experiments below, made by Mr. Hodgkinson, that no difficulty will be found in ascertaining the strength due to any size or form of column that may be required.

Round Columns of Plate Iron Rivetted,

Columns 10′ 0″ long.					Same Columns Reduced in Length.	
Diameter.	Thickness.	Proportion of Thickness to Diameter.	Proportion of Length to Diameter.	Breaking Weight.	Breaking Weights. 5′ 0″ long.	Breaking Weights. 2′ 6″ long.
				Tons per sq. in.	Tons per square inch.	
$1\frac{1}{2}$	·1	$\frac{1}{15}$	80 to 1	6·5	13·9	5·8
2	·1	$\frac{1}{20}$	60 to 1	10·35	14·8	16·5
$2\frac{1}{2}$	·1	$\frac{1}{25}$	48 to 1	13·3	15·6	16·3
"	·24	$\frac{1}{11}$	"	9·6	"	16
"	·21	$\frac{1}{12}$	"	9·9	13·	17
3	·15	$\frac{1}{26}$	40 to 1	12·36	"	16·5
4	·15	$\frac{1}{26}$	30 to 1	12·34	"	
6	·1	$\frac{1}{60}$	20 to 1	15·	17	18·6
6	·13	$\frac{1}{46}$	"	18·6		

It would seem from this that a thickness of $\frac{1}{48}$, or $\frac{1}{4}''$ in thickness for every foot in diameter is a good proportion for this kind of column.

Square Columns of Plate Iron Rivetted,

Size.	Thickness.	Proportion of Thickness to Width.	Proportion of Length to Width.	Breaking weight Tons per sq. in. of section.
Columns 10′ 0″ long.				
4″ × 4″	·03	$\frac{1}{133}$	30 to 1	4·9
"	·06	$\frac{1}{66}$	"	8·6
"	·1	$\frac{1}{40}$	"	10
"	·2	$\frac{1}{20}$	"	12
8″ × 8″	·06	$\frac{1}{133}$	15 to 1	6
"	·14	$\frac{1}{60}$	"	9
"	·22	$\frac{1}{36}$	"	11·5
"	·25	$\frac{1}{32}$	"	12
Column 8′ 0″ long.				
18″ × 18″	·5	$\frac{1}{36}$ practically	5·4 to 1	13·6

Column 10′ 0″ *long, with Cells.* 				
Size.	Thickness.	Proportion of Thickness to Width.	Proportion of Length to Width.	Breaking weight Tons per sq. in. of section.
8″ × 8″	·06	$\frac{1}{66}$ of width of cells	15 to 1	8·6

To find the strength of any hollow wrought iron column.

Sec. area, sq. ins. × Tons per inch, corresponding to the proportions of length and thickness to width as per tables = Breaking weight, tons.

It will be seen from these experiments, that it is the proportion of thickness to the width of cell which regulates the strength within certain limits of height.

And that a thickness of $\frac{1}{30}$ or $\frac{1}{8}$″ for every 4 ins. in width will give the highest result practicable for square columns.

Columns of Oblong Section, 

The strength of these may be ascertained by the same rule as that of square columns. The smallest width being taken in calculating the proportion of height to width, while the longest side must be taken into consideration in calculating the proportion of thickness to width.

Column 10′ 0″ *long.*				
Size.	Thickness.	Proportion of Thickness to greatest Width.	Proportion of Length to least Width.	Actual Breaking Weight Tons per sq. in. of Section.
8″ × 4″	·06	$\frac{1}{133}$	30 to 1	6·78

The experiments in detail on hollow wrought iron columns will be found in Mr. Edwin Clark's work on the Britannia and Conway tubular bridges.

CONDENSOR.

As a maximum, made of equal capacity with the cylinder.

As a minimum, of equal capacity with the air pump.

For marine engines working at a good pressure, and carrying steam through the whole stroke, about $\frac{2}{3}$ of contents of cylinder is a good proportion. If the steam is expanded and reduced to the pressure of the atmosphere at the end of the stroke, $\frac{1}{2}$ contents of cylinder; minimum for marines in any case, $\frac{1}{3}$ contents of cylinder.

In land engines, where the pressure is always more reduced, and more equable, and where the condensor is altogether surrounded by water, a smaller size is found to be quite sufficient; and the proportion may vary, according to the room at disposal, and the pressure of steam, from $\frac{1}{2}$ to $\frac{1}{6}$ the capacity of the cylinder.

In marine engines it is important that the condensor should be of considerable height, and that it should be compact at the bottom. If made shallow, when the vessel is rolling or pitching heavily, the water is apt to get out of the reach of the pump at the proper time, and to accumulate so as to make the air-pump work heavily and unevenly, occasionally to such an extent as to cause injury to the pump. With a deep condensor the injection water can be better dispersed through the steam, and the water accumulates in a compact body, ready for the pump to act upon at any time.

For double-acting air pumps, in order to make them act with efficiency on both up and down strokes, the condensor should be so arranged, if possible, that the bottom of the condensor may be at least as high as the top part of the pump.

CRANE.

The strains on the principal parts can be ascertained with great ease in the following manner — the strength being proportioned accordingly.

To find the strain on the post.

$$\frac{\text{Weight suspended, tons} \times \text{Projection, feet}}{\text{Height of post above ground, feet.}} = \text{Strain on top of post, tons.}$$

The post can then be calculated as a beam, twice as long as this height from ground, with twice the weight on the middle. (See BEAMS, p. 3.)

To find the strain on the jib and tension rods.

On the sketch of the crane, mark off on the chain a distance by scale equal to the weight on the chain; from this point draw a line parallel to the tension rod, and where this intersects the jib, draw another vertical line.

The distances from the end of the jib to the points thus intersected on the jib, and tension rods, will represent the proportionate strains.

The strains on the annexed sketch being respectively—

10 tons weight on the chain.
31 „ strain on the jib, compressively.
26 „ „ on the tension rods.

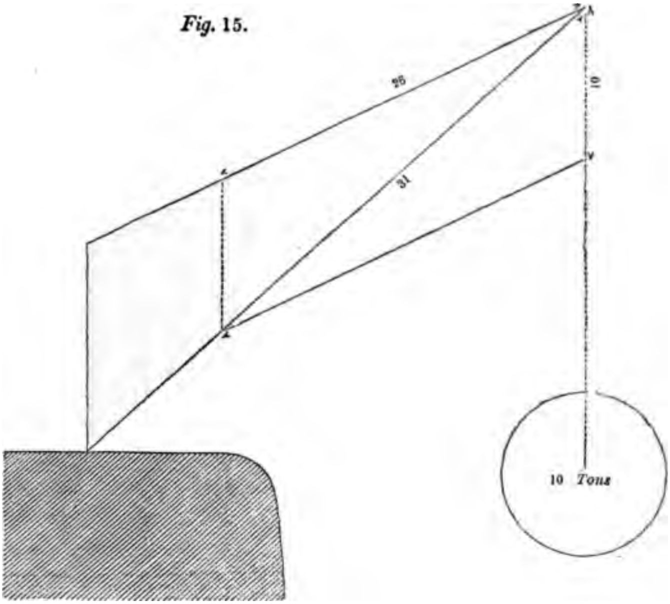
The jib can then be calculated as a column with the ends rounded one way. (See COLUMNS.)

Under ordinary circumstances a crane should not be loaded with more than $\frac{1}{8}$ of the breaking weight; if however fitted without a brake, so that the weight can only be lowered by hand, it may be loaded with $\frac{1}{6}$, and the parts may be proportioned accordingly.

14 lbs. on the handle is the outside to allow for intermittent work.

10 lbs. on the handle is sufficient, if intended for continuous work.

Fig. 15.



Handles. 1′ 4″ to 1′ 6″ radius. 1′ 3″ to 2′ 6″ long.

Height. About 3′ 0″ to 3′ 2″ from the ground is the most convenient.

Wheelwork. (See WHEELS.)

ENGINE.

To find the effective horse power.

$$\frac{\text{Area cyl. ins.} \times (\text{aver. press.}-\text{friction, lbs.}) \times \text{speed piston ft. per min.}}{33{\cdot}000} = \text{HP.}$$

For the friction the Table annexed will give a fair approximation.

TABLE OF FRICTION OF ENGINES.

Diameter Cyl. ins.	Oscillating and Trunk.	Beam and Geared.	Direct Acting and Vertical.
	lbs. per sq. in.	lbs.	lbs.
10	5	6	7
15	4	5	6
20	$3\frac{1}{2}$	4	5
25	3	$3\frac{1}{2}$	$4\frac{1}{2}$
30	3	$3\frac{1}{2}$	4
35	$2\frac{1}{2}$	3	$3\frac{1}{2}$
50	$2\frac{1}{2}$	$2\frac{1}{2}$	3
60	2	$2\frac{1}{2}$	3
70	2	$2\frac{1}{2}$	$2\frac{1}{2}$
80	2	2	$2\frac{1}{2}$
100	$1\frac{1}{2}$	2	$2\frac{1}{2}$
110	$1\frac{1}{2}$	2	2

To find the friction of any larger or smaller size.

$$\left.\begin{array}{r}\text{Oscillating and}\\ \text{Trunk Engines}\end{array}\right\} \frac{15}{\sqrt{\text{diam. cyl. ins.}}} = \text{Friction, lbs. per sq. in.}$$

$$\text{Beam and Geared} \frac{18}{\sqrt{\text{diam. cyl. ins.}}} = \text{Friction, lbs. per sq. in.}$$

$$\left.\begin{array}{r}\text{Direct-acting}\\ \text{and Vertical}\end{array}\right\} \frac{21}{\sqrt{\text{diam. cyl. ins.}}} = \text{Friction, lbs. per sq. in.}$$

TABLE OF THE ORDINARY SIZES OF ENGINES.

High Pressure.		
Nominal H. Power.	Diam. Cyl. ins.	Sq. ins. per Nom. H. P.
6	9	10
10	11½	"
15	14	"
20	16	"
30	19	9
40	21½	"
50	24	"
60	26	"

Marine and Condensing.		
Nominal H. Power.	Diam. Cyl. ins.	Sq. ins. per Nom. H. P.
15	20	28
20	25	25
40	36	"
60	42	22
100	51	20
150	62	"
200	72	"
Above 200	. .	19
Above 300	. .	18

With a stroke of 1 to 1½ times diameter for marine and condensing engines respectively, and of 2½ to 3 times diameter for high pressure engines. A little more area being allowed if the stroke is made less than the above proportion, and less area if the stroke be larger.

PROPORTIONS OF ENGINES.

The following will be found good proportions for the main parts.

BEAM.—For Marines. Length, 2½ to 3 times stroke.
Land engines " 3 times stroke.
Depth, ½ stroke.
Thickness, $\frac{1}{16}$ of depth.

CONNECTING ROD.—Length, 2 to 3 times stroke.

The length should not be less than twice in any case, and there appears to be no advantage in having it more than 3 times.

Diameter at neck=piston rod, is sufficient as far as strength is concerned.

Swelling, $\frac{1}{8}''$ to $\frac{1}{4}''$ per foot. $\frac{3}{16}$ is a good medium.

CRANK.—Depth of large eye = diameter of shaft.
Metal round eye $= \frac{1}{3}$ ditto.
Depth of small eye = ·7 of shaft's diameter.
Metal round ditto $= \frac{1}{2}$ diameter of crank pin.

CRANK PIN.—Diameter, $1\frac{1}{4}$ to $1\frac{1}{3}$ diameter of piston rod.
Length $1\frac{1}{4}$ to $1\frac{1}{2}$ its own diameter.

It is always advisable to have a good size and surface, as it thus becomes less liable to heat.

CROSSHEAD.—Depth at eye, 3 times diameter of rod.
Thickness, $\frac{1}{4}$ of depth.

MAIN CENTRE.—Diameter $= 1\frac{1}{2}$ times diameter of piston rod.

PORTS.—Steam $\left\{\begin{array}{l}\text{width} = \frac{1}{2}\text{ diam. of cyl.}\\ \text{depth} = \frac{1}{6}\text{ of width}\end{array}\right\} = \frac{1}{20}$ of cyl. area.
Exhaust, depth $= \frac{1}{3}$ to $\frac{1}{4}$ of width.

For engines running at the highest speed Locomotives, &c.	$\frac{1}{14}$ of cyl. area.
Direct-acting screw boat engines .	$\frac{1}{18}$ "
Ordinary marine engines . . .	$\frac{1}{20}$ "
Ordinary land engines running only at 200 feet per min.	$\frac{1}{25}$ "

PISTON ROD.—$\frac{1}{10}$ of diam. of cyl. for condensing engines.
$\frac{1}{6}$ to $\frac{1}{7}$ of ditto for high pressure.

PARALLEL MOTION RODS.—Piston rod × ·3

SHAFT.—If of wrought iron, Piston rod × 2 to $2\frac{1}{8}$.

STEAM PIPE.—Area equal to that of steam ports.

VALVE SPINDLE.—Piston rod × ·4.

VALVE SHAFT.—Piston rod × ·9.

EXPANSION OF STEAM.

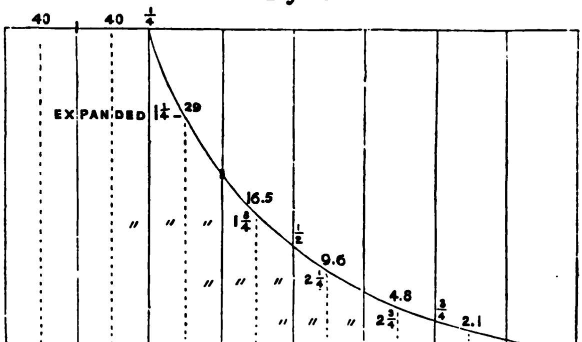
To find the pressure at any particular point of expansion.

$$\frac{\text{Pressure before expansion, lbs.} + 14 \cdot 7}{\text{No. of times the steam is expanded.}} - 14 \cdot 7 = \text{Pressure required, lbs.}$$

To find the average pressure.

Construct a rough diagram as per sketch annexed, which is of 40 lbs. cut off at $\frac{1}{4}$, and divide it into a suitable number of parts for calculation; find the pressure due to each stage of expansion; add these together and divide by the number of parts the diagram is composed of, the result gives the average pressure on the whole.

Fig. 16.



$$\begin{array}{rr}
 & 40 \\
 & 40 \\
 & 29 \\
 & 16\cdot5 \\
 & 9\cdot6 \\
 & 4\cdot8 \\
 & 2\cdot1 \\
\hline
 & 142\cdot0 \\
\text{Deduct} & \cdot2 \\
\hline
8) & 141\cdot8 \\
\hline
 & 17\cdot7 \text{ average pressure.}
\end{array}$$

This theoretic diagram will not correspond quite exactly with the real diagram of an engine in any case; it will however very nearly, if the steam be shut off close to the port, if the valve and piston be tight, and if the steam be fully protected from condensation by steam jacket or otherwise; but in ordinary engines, where the expansion valve is behind the casing, the whole steam in the casing expands with that in the cylinder, and alters the proportion of expansion materially.

For instance,—suppose the contents of casing and passages to be only $\frac{1}{10}$ that of the cylinder, and the steam to be cut off when the piston has moved $\frac{1}{4}$ of its stroke, the steam expanding will then be to the whole contents of the cylinder and casing as 3·5 to 1·1; so that the steam will only expand 3 times instead of 4 times.

In order to see clearly the advantage in an economical point of view of using steam expansively, and in order to compare the effective value of different kinds of engines working under different circumstances as to pressure, expansion, and speed, it is necessary in the first place to bring them all to some common basis.

This basis should be—

Effective Horse Power obtained from every cubic foot of Water evaporated per hour. (There is no use in going further than this as far as the engine is concerned.)

The number of lbs. coal consumed per cubic foot of water evaporated depends upon the boiler. (See Boiler.)

From engine and boiler combined, we come to a final simple basis of lbs. coal per Horse Power per hour.

To find the evaporation of water required to supply any engine with steam.

Find the actual quantity of steam in cubic feet contained in the cylinder, passages, and casing, up to the point where the steam is cut off.

Then $\frac{\text{Cub. ft. in cyl. thus found} \times \text{revolutions per min.}}{\text{No. in table corresponding to pressure.}} =$
Cubic feet of water to be evaporated per hour.

Pressure.	Divisor.	Pressure.	Divisor.	Pressure.	Divisor.
2·5 lbs.	12·47	20	6·4	80	2·6
3	12·1	25	5·6	90	2·36
4	11·4	30	5·	100	2·2
5	10·7	35	4·6	120	1·9
6	10·	40	4·2	135	1·7
8	9·4	45	3·9	150	1·56
10	8·7	50	3·6	165	1·4
12	8·1	55	3·4	180	1·3
14	7·6	60	3·2	195	1·25
16	7·1	65	3	210	1·17
18	6·75	70	2·8	235	1·1

For table in detail from which this divisor is derived, see FEED PUMP.

ECONOMY OF EXPANSION.

To show the comparative economical result derived from using steam expansively, we will take an ordinary condensing engine of 30 horse power, under two or three different rates of pressure and expansion, and reduce the result to the above basis of Horse Power per cubic feet of water evaporated.

Engine cylinder 30″ diam. 4′ 0″ stroke; 25 revolutions; vacuum average 12½ lbs.

Cylinder 707″ area; 19·6 cubic ft. contents; passages and casing say $\frac{1}{6}$=3·2 cubic feet.

1st. Engine working with steam of 7 lbs.; full steam for ¾ of the stroke, till cut off by the slide valve. Average pressure on steam side 6 lbs —

$$\frac{707 \times (18\frac{1}{2} - 3\frac{1}{2} \text{ friction}) \times 200 \text{ speed}}{33{,}000} = 64 \text{ H.P. effective.}$$

The evaporation of water to supply the cylinder being 37·3 cubic feet per hour, see Rule on previous page.

Economical result: 1·7 Horse Power for every cubic foot of water evaporated.

2nd. Engine working with steam of 25 lbs. cut off at $\frac{1}{4}$ stroke, by means of an ordinary expansion valve behind the casing —

The actual expansion, taking the steam in the casing into account, will be 2·8 to 1; giving an average pressure on the piston of 12 lbs. per inch —

$$\frac{707 \text{ area} \times (12 \text{ av.} + 12\tfrac{1}{2} \text{ vac.} - 3\tfrac{1}{2} \text{ fric.}) \times 200}{33{,}000} = 90 \text{ H.P. eff.}$$

The evaporation required to supply the cylinder being 36 cubic feet per hour.

Economical result: 2·5 Horse Power per cubic foot of water evaporated.

3rd. Engine working with steam of 25 lbs. cut off at $\frac{1}{4}$ stroke, but cut off close to the port instead of behind the casing —

The average pressure on the piston will be 9 lbs. per sq. in.

And the result will be 77 Horse Power effective;

Evaporation required being 22 cubic feet per hour;

Economical result: 3·5 Horse Power per cubic foot of water evaporated.

The last arrangement giving just double the economical result of the first arrangement of the same engine, or in other words, developing an equal power with the first with half the expenditure of fuel.

The following table shows the average pressure, and the relative economy, derived from the different pressures and degrees of expansion.

TABLE OF EXPANSION OF STEAM AND COMPARATIVE ECONOMICAL EFFECT.

Initial Pressure.	Cut off at	Average Pressure.	High Pressure Engines. Gross H. P. per cubic ft. of water evaporated.	Condensing Engines, including 13 lbs. vacuum. Gross H. P. per cubic ft. of water evaporated.
7 lbs.	$\frac{2}{3}$	5·5		2·18
10	$\frac{2}{3}$	8·4		2·23
15	$\frac{2}{3}$	12·8	1·13	2·27
"	$\frac{1}{2}$	10·2	1·35	2·7
"	$\frac{1}{3}$	5·8	1·02	3·29
"	$\frac{1}{4}$	2·8	·65	3·69
"	$\frac{1}{6}$	−1·2		3·83
"	$\frac{1}{12}$	−4·8		4·88
20	$\frac{2}{3}$	17·7	1·36	2·35
"	$\frac{1}{2}$	14·7	1·5	2·83
"	$\frac{1}{3}$	9·4	1·44	3·44
"	$\frac{1}{4}$	5·7	1·18	3·84
"	$\frac{1}{6}$	1·2	·38	4·36
25	$\frac{2}{3}$	22·8	1·54	2·41
"	$\frac{1}{2}$	19·1	1·63	2·87
"	$\frac{1}{3}$	13·4	1·8	3·55
"	$\frac{1}{4}$	9	1·62	3·94
"	$\frac{1}{6}$	3·3	·91	4·39
40	$\frac{2}{3}$	36·4	1·83	2·49
"	$\frac{1}{2}$	31·4	2·11	2·98
"	$\frac{1}{3}$	23·4	2·36	3·67
"	$\frac{1}{4}$	17·5	2·35	4·1
"	$\frac{1}{6}$	10·2	2·07	4·76
"	$\frac{1}{8}$	5·9	1·59	5·08
60	$\frac{2}{3}$	55·1	2·03	
"	$\frac{1}{2}$	48·5	2·47	3·15
"	$\frac{1}{3}$	37·2	2·86	3·86
"	$\frac{1}{4}$	29·8	3·05	4·39
"	$\frac{1}{6}$	19·2	3·15	4·93
"	$\frac{1}{8}$	13·4	2·74	5·41

Initial Pressure.	Cut off at	Average Pressure.	High Pressure Engines. Gross H. P. per cubic ft. of water evaporated.	Condensing Engines, including 13 lbs. vacuum. Gross H P. per cubic ft. of water evaporated.
80	$\frac{2}{3}$	73·8	2·31	
"	$\frac{1}{2}$	65·2	2·71	
"	$\frac{1}{3}$	51·5	3·22	4·02
"	$\frac{1}{4}$	40·6	3·37	4·46
"	$\frac{1}{6}$	28·65	3·58	5·2
"	$\frac{1}{8}$	20·9	3·48	5·72
"	$\frac{1}{10}$	15·8	3·29	6·
100	$\frac{2}{3}$	90·4	2·93	
"	$\frac{1}{2}$	80·6	2·84	
"	$\frac{1}{3}$	63·4	3·35	
"	$\frac{1}{4}$	52·	3·67	
"	$\frac{1}{6}$	37·7	3·99	
"	$\frac{1}{8}$	28·5	4·02	
"	$\frac{1}{10}$	22·4	3·95	

To find the economical effect of any other rate of expansion.

$$\frac{(\text{Average steam pres.} + 13 \text{ lbs. for condensing eng.}) \times \text{No. of times steam is expanded}}{\text{No. in table below, corresponding to initial pressure}}$$

= Economical effect. Gross H.P. per cubic feet water evaporated.

Initial Pressure.	Divisor.	Initial Pressure.	Divisor.	Initial Pressure.	Divisor.
2·5 lbs.	10·02	20 lbs.	19·53	80	48·07
3	10·33	25	22·32	90	52·11
4	10·96	30	25·	100	56·8
5	11·68	35	27·17	120	65·79
6	12·5	40	29·76	135	73·53
8	13·3	45	32·05	150	80·12
10	14·37	50	34·72	165	89·28
12	15·43	55	36·76	180	96·15
14	16·44	60	39·06	195	100·
16	17·6	65	41·7	210	106·83
18	18·51	70	44·64	235	113·6

The foregoing table also being derived from the Table of Volumes, see page 55.

To find the Effective Horse Power per cubic foot of water evaporated.

Find the proportion the friction due to the particular size and form of the engines, as per table page 38, bears to the average steam pressure (+vacuum for condensing engines), and deduct this proportion from the gross H.P. per cubic foot of water evaporated, as found above: the result will be Effective H.P. per cubic foot of water evaporated.

For instance, take an engine with steam of 20 lbs. cut off at $\frac{1}{4}$, and with $3\frac{1}{2}$ lbs. friction:

The average pressure 5·7 lbs. + 13 vacuum is 18·7 lbs.

The friction here is $\frac{1}{5{\cdot}3}$ of the average pressure.

$\frac{1}{5{\cdot}3}$ deducted from 3·84 gross H.P. = 3·12 effective H.P. per cubic ft. water evaporated.

Or in another form, perhaps simpler.

$$\frac{\text{Gross H.P. per cub. ft. water evaporated} \times \text{actual pressure, after deducting friction as per table, page 38.}}{\text{Total average steam pressure} + 13\text{lbs. for condensing engines}} = \text{Effective H.P. per cub. ft. water evaporated.}$$

The above Table of comparative economical effect of pressures and expansions shows clearly and conclusively:

1st. That the rate of expansion being the same, the higher the pressure is, the greater is the economical effect, whether in Condensing or in Non-Condensing engines;

2nd. That in Non-Condensing engines, the most economical result is obtained, when the steam is cut off at such a point that the pressure is reduced to that of the atmosphere at the end of the stroke:

That is	25 lbs.	cut off at	$\frac{1}{3}$	of stroke.
"	40 "	"	$\frac{1}{4}$	"
"	60 "	"	$\frac{1}{5}$	"
"	80 "	"	$\frac{1}{6}$	"
"	100 "	"	$\frac{1}{8}$	"
"	130 "	"	$\frac{1}{10}$	"

3rd. That in Condensing engines the sooner the steam is cut off, the more economical is the result.

The greatest attention should be paid to the principles indicated above in constructing engines of any sort.

The degree of expansion being properly arranged, according to the pressure that can be conveniently obtained and the work required to be done; and the strength of the engine being proportioned to the initial pressure; the only disadvantage connected with using steam expansively is the considerable difference between the pressures at the different parts of the stroke. It is not at all clear however, that the difference of speed of the piston at the different parts of the stroke does not entirely correct this inequality of pressure. At the beginning of the stroke, while the pressure is high, the speed of the piston is very low, afterwards the pressure decreases while the speed is increasing; while the momentum previously acquired comes into play, when the speed decreases again. The force developed being probably more equable than otherwise. At all events any inequalities may be corrected quite sufficiently for all practical purposes, by having a well-proportioned flywheel, or by using two engines coupled together.

MODES OF EXPANSION.

Every engineer will be acquainted with some mode of expansion, though the arrangements in ordinary use in this

country are far from being satisfactory. In marine engines, double conical valves, put *behind* the casing, and worked by cams, being the most general plan, throttle valves sometimes being used instead of equilibrium valves; occasionally a separate slide working behind the slide valve is used, for small engines, this last saves the steam in the casing, and is so far an improvement.

In land engines, the double cylinder arrangement is perhaps the most in use, but is a complicated and expensive plan, besides which it does not allow of the extension of power which can be attained with a single cylinder, and which is often found most convenient and desirable. Mr. Fairbairn has a very efficient arrangement in his improved engines; but the slide valve is still far too much in vogue.

A slight description of the usual plans adopted in America, where a great deal of attention is paid to this point, both in their river boat engines, and their land engines, may not be without use or interest.

The usual arrangement for the fast running boats on the Hudson, is to have double beat conical valves working close to the port, a steam and exhaust pair to each port, the steam valves worked by one eccentric, the exhaust by another, the valves being lifted by means of wipers on the valve shaft. The steam eccentric and wipers are so arranged, that the valve is not opened till the eccentric is nearly at the end of its stroke, consequently allowing the valve to shut very soon again, cutting off at whatever fixed part of the stroke may be thought desirable: the wiper carrying the weight of the valve and rod till it reaches its seat again. The exhaust eccentric and wipers are so arranged that one exhaust is always open.

Another plan used on the Hudson is to have both steam and exhaust valves worked by the same eccentric: the exhaust being arranged to open a little sooner than the steam valve; the steam valve being arranged so as to detach itself at a certain part of the stroke, and to fall down and shut

itself; in due course the rod falls down to shut the exhaust, and the steam valve connects ready for lifting again. When this arrangement is used, the spindle of the steam valve is made to drop into a small close box full of water, which breaks its fall, and eases it down upon its seat. With this cut off, the rate of expansion can be varied with the greatest facility.

On the Ohio and Mississippi, where horizontal engines are mostly in use, they also have conical valves, generally but not always double, placed close to the ports, lifted by long levers the ends of which nearly meet over the middle of the cylinder; the wiper shaft in two halves being arranged to work all the levers; the steam and exhaust valves being worked by separate cams of peculiar shape on the shaft.

In smaller boats slide valves are used, the slide being made with a large exhaust and a great deal of cover, worked by a cam so arranged as just to cut off the steam at whatever point may be required, leaving the exhaust still open; and the valve works in two jumps instead of continuously.

The great ease with which these double conical valves can be handled is a point of some importance, especially in large engines.

On the Hudson, and also in Cornwall, where the same description are universally used on the pumping engines, though worked in a different manner to suit the purpose required, the engines of the largest size, 80″ diameter and 12 feet stroke and upwards, can be handled by one man with the greatest ease.

For engines running very fast, such as locomotives and screw boat engines, the slide valve worked by the link motion is nearly universally used; and, if properly arranged, is a very efficient expansion apparatus for these purposes.

SPEED OF ENGINES.

It will always be found advantageous in point of economy to arrange for running an engine at as great a speed as can be maintained without heating, undue friction, or shaking.

The same power is gained with a less expenditure of steam, or a greater power with an equal expenditure, in consequence of the engine getting the benefit of the steam expansion, which it will do whether it be properly fitted with expansion valve, or merely throttled.

Ft. per min.	
200	may be the minimum for any purpose,
250	a good speed for land engines with a fair stroke,
250 to 300	for marine paddle-wheel engines and geared screw engines,
300 to 400	for direct-acting screw engines, well balanced and secured,
500 to 600	ordinary speed on the Hudson for engines 10 feet stroke and upwards,
Up to 1000	for locomotives.

To show in a practical manner the economical effect of running an engine fast.

We will take any condensing engine, with a boiler capable of evaporating 100 cubic feet of water per hour at a pressure of 20 lbs. per inch. Suppose the engine to have $2\frac{1}{2}$ lbs. friction, and the steam to be cut off close to the ports.

Suppose this evaporation be sufficient to supply the cylinder $\frac{3}{4}$ full of steam when running at 180 feet per minute, the same evaporation at higher speeds will give the following results :—

Speed. Feet per Minute.	Steam. cut off.	Effective Average Pressure. Steam. Vacuum. Friction.	Total.	Effective Horse-power.
180	$\frac{2}{3}$	$17{\cdot}7+13-2{\cdot}5$	28·2 lbs.	216
225	$\frac{1}{2}$	$14{\cdot}7+13-2{\cdot}5$	25·2	257
270	$\frac{1}{3}$	$9{\cdot}4+13-2{\cdot}5$	19·9	306
450	$\frac{1}{4}$	$5{\cdot}7+13-2{\cdot}5$	16·2	333
540	$\frac{1}{6}$	$1{\cdot}2+13-2{\cdot}5$	11·7	360

FAN.

Case should be strong and heavy. Bearings long. Blades and arms as light and well balanced as possible.

Good proportions—

Inlet $=\frac{1}{2}$ diam. of fan,

Blades $=\frac{1}{4}$ diam. of fan each way,

Outlet $=$ area of blades.

The area of tuyeres is most advantageous when made

$$=\frac{\text{area of blades}}{\text{density of blast, oz. per sq. in.}}$$

and it should not exceed double this size.

VELOCITY OF FANS.

THE BEST VELOCITY OF CIRCUMFERENCE FOR DIFFERENT DENSITIES.

Velocity of Circumference. Feet per Second.	Density of Blast. Oz. per Inch.
170	3
180	4
195	5
205	6
215	7

A speed of 180 to 200 feet per second, giving a density of 4 or 5 oz., is very suitable for smithy fires.

250 to 300 feet per second is a proper speed for cupolas.

A fan 4′ 0″ diameter, blade 1′ 0″ square, will supply 40 fires with 1⅝ tuyeres at a density of 4 oz.

To find the Horse Power required for any fan,

Let D = density of blast in oz. per inch.

A = area of discharge at tuyeres in square inches.

V = velocity of circumference in feet per second.

$$\text{Then } \frac{\frac{V^2}{1000} \times D \times A}{963} = \text{Effective Horse Power required.}$$

To find the density to be attained with any given fan,

Let d = diameter of fan in feet.

$$\text{Then } \frac{\left(\frac{V}{4}\right)^2}{120 \times d.} = \text{Density of blast in oz. per inch.}$$

Or the density may be found by comparison with the following table:—

Velocity of Circumference. Feet per Second.	Area of Nozzles.	Density of Blast. Oz. per Inch.
150	Twice area of blades	1
„	Equal ditto	2
„	½ ditto	3
170	¼ ditto	4
200	½ ditto	4
„	⅙ ditto	6
220	⅓ ditto	6

To find the quantity of air that will be delivered by any fan, the density being known.

Total area nozzles, sq. ft. × velocity, ft. per min. corresponding to density (as per table) $= \left\{ \begin{array}{l} \text{Air delivered, cubic} \\ \text{ft. per min.} \end{array} \right.$

Density. Oz. per Sq. Inch.	Velocity. Feet per Minute.	Density. Lbs. per Sq. Inch.	Velocity. Feet per Minute.
1	5,000	1	20,000
2	7,000	$1\frac{1}{2}$	24.500
3	8,600	2	28,3C0
4	10,000	$2\frac{1}{2}$	31,600
5	11,000	3	34,640
6	12,250	4	40,000
7	13,200	6	49,000
8	14,150	8	56.600
9	15,000	10	63,200
10	15,800	12	69,280
11	16,500	15	78,000
12	17,300	20	89,400

FEED PUMP.

For condensing engines, usually—

$\frac{1}{12}$ of cyl. diam. when $\frac{1}{2}$ stroke of piston.

$\frac{1}{9}$ " $\frac{1}{4}$ "

High-pressure engines—

$\frac{1}{9}$ of cyl. diam. when $\frac{1}{2}$ stroke of piston.

$\frac{1}{7}$ " $\frac{1}{4}$ "

To find the proper size under all circumstances capable of supplying three times the quantity of water required by the cylinder.

$$\frac{\text{Area of cyl. sq. ins.} \times \text{length of stroke before steam is cut off, feet} \times 6}{\text{Tabular No. corresponding to pressure in boiler} \times \text{stroke of pump, ft.}}$$
$=$ Area of pump, sq. ins.

TABLE OF VOLUMES OF STEAM PRODUCED BY ONE OF WATER.

Pressure. lbs. per sq. inch.	Volume of Steam to 1 of Water.	Pressure. lbs. per sq. inch.	Volume of Steam to 1 of Water.	Pressure. lbs. per sq. inch.	Volume of Steam to 1 of Water.
2·5	1496	20	767	80	310
3	1453	25	678	90	283
4	1366	30	609	100	264
5	1282	35	553	120	224
6	1225	40	506	135	203
8	1127	45	468	150	187
10	1044	50	435	165	173
12	973	55	407	180	161
14	911	60	382	195	150
16	857	65	362	210	141
18	810	70	342	235	133

In marine engines, it is advantageous to arrange so that the pump may be disconnected without stopping, in the same manner as the bilge pump (see page 10); and the feed valve boxes should be placed clear of the engine, so that the valves can be overhauled at any time.

For regulating the feed in single boilers, a cock on the suction pipe is the simplest plan; a check valve being put close to the boiler, so that the valve box may be overhauled at any time.

For marine engines, a check valve close to the boiler, the lift of which is regulated by a screw stop, is preferable to a cock.

The size of the valves should be so arranged that the speed of water passing through may not exceed 500 feet per minute. If arranged at 250 or 300 feet per minute, they will work quietly and comfortably; that is, for a pump working at 100 feet per minute, the area of valve should be $\frac{1}{3}$ of the pump's area; at 50 feet per minute, $\frac{1}{6}$; and so on.

FLY WHEEL.

Diameter, 3 to 5 times the stroke of engine: 4 times is a good proportion.

Weight of rim about 3 cwt. per horse power.

To find the proper weight under any circumstances.

$$\frac{\text{Area cyl. ins.} \times \text{average pressure on piston, lbs.} \times \text{stroke, ft.}}{\text{Diameter wheel, feet} \times 45}$$

$=$ Weight of rim, cwts. suitable for ordinary circumstances.

If a light wheel is required, use 60 as divisor instead of 45.

If a heavy one, „ 30 „ „ „

The principle being that the momentum of the wheel should be from 3 to 6 times the average momentum of the piston.

The weight and diameter being determined on, to find the size of rim.

$$\frac{\text{Weight cwts.} \times 11{\cdot}4}{\text{Mean diam. of rim, feet}} = \text{Sectional area, sq. ins.}$$

When the work is steady and the engine well balanced, a light wheel will be sufficient; with irregular work, or an unbalanced engine, the wheel should be heavier; and for some purposes—rolling mills, sugar mills, &c.—the wheel can hardly be made too heavy. Engines working at a very high rate of expansion also require heavy wheels.

FRICTION.

From Mr. Rennie's Experiments.

The friction of metal on metal, without unguents,

May be taken at	$\frac{1}{6}$ of the	weight	up to	40 lbs.	per sq. in.
„	$\frac{1}{5}$	„	„	100	„
Brass on cast iron	$\frac{1}{4}$	„	„	800	„
Wrought on cast iron	$\frac{1}{3}$	„	„	500	„

With tallow at $\frac{1}{10}$ of the weight.

„ olive oil at $\frac{1}{13}$ „

800 lbs. per inch forces out the oil.

Friction of journals under ordinary circumstances $\frac{1}{30}$ of wght.

„ well oiled, sometimes only $\frac{1}{60}$ „

Friction of Engines, see page 38.

GOVERNOR.

Let L be the vertical height, ins. between plane of balls and points of suspension.

$\frac{188}{\sqrt{L}}$ = Revolutions per minute required to maintain the balls at that height.

And $\left(\frac{188}{\text{Revs. per min.}}\right)^2$ = Length or vertical height, ins.

The amount of variation may be $\frac{1}{10}$ to $\frac{1}{15}$ of the mean velocity. Suppose a governor be adapted for 30 revolutions as a mean speed, at 29 revolutions it should open the valve wide; at 31 revolutions it should close it altogether.

GUDGEONS.

See SHAFTS.

HEAT.

EFFECTS OF HEAT AT CERTAIN TEMPERATURES.—GRIER.

	Fahrenheit.
Tin and Bismuth, equal parts, melt at .	283°
Tin melts	442
Polished steel acquires straw colour . .	460
Bismuth melts at	476
Sulphur burns	560
Oil of turpentine boils	„
Polished steel acquires deep blue colour .	580
Lead melts	594
Linseed oil boils	600
Quicksilver boils	660
Zinc melts	700
Iron, bright red in the dark . . .	752
„ red-hot in twilight	884
Red heat fully visible in daylight . .	1077
Brass melts	3807
Copper melts	4587
Silver melts	4717
Gold melts	5237
Welding heat of iron, from . . .	12777
„ to	13427
Greatest heat of smith's forge . . .	17327
Cast iron begins to melt	17977
„ thoroughly melted . . .	20577

INJECTION.

Injection pipe $\frac{1}{9}$ to $\frac{1}{15}$ of cylinder's diameter.

$\frac{1}{9}$ of cylinder's diameter being the proportion used in the steamers on the Hudson, working with 20 to 35 lbs. steam, and running 450 to 600 feet per minute.

$\frac{1}{15}$ usual proportion for marines, working with 10 to 15 lbs. steam, and running 200 feet per minute.

To find the proper size under any circumstances capable of supplying three times the quantity used.

$$\frac{\text{Cubic ft. water used in cylinder per hour in form of steam.}}{9}$$

= Area of injection, sq. ins.

For Rule, see page 42.

9 is divisor when the steam is expanded down to the atmosphere on reaching the condensor.

8·9 is divisor when the steam is equal to 5 lbs. per inch.

8·8 „ „ „ 10 „

8·7 „ „ „ 20 „

The above simple rule is deduced from the following :—

To find the quantity of water required to condense a given amount of steam.

Let C = temperature of condensing water.

S = temperature of steam corresponding to pressure as per table below.

$$\text{Then } \frac{900+S}{100-C} = \left\{ \begin{array}{l} \text{The number of cub. ft. of water re-} \\ \text{quired to condense each cubic foot of} \\ \text{water in the form of steam used in the} \\ \text{cylinder.} \end{array} \right.$$

Pressure. lbs. above atmosphere.	Temperature. Fahrenheit.	Pressure. lbs.	Temperature. Fahrenheit.
2	219°	16	253°
4	225	18	257
6	231	20	260
8	236	25	269
10	240	30	276
12	245	35	283
14	249	40	289

The temperature of condensing water is taken as generally 52°.

The quantity of water used in cylinder is found by Rule, page 42.

To find the size of pipe necessary to supply a given quantity of water.

$$\frac{\text{Cub. ft. water required per min.}}{\text{Velocity due to vacuum as per table}} = \left\{\begin{array}{l}\text{Area of pipe, square feet,}\\ \text{making no allowance for}\\ \text{friction.}\end{array}\right.$$

If 1500 be taken as divisor, it allows $\frac{1}{7}$ for friction with a vacuum of 13 lbs., and if the injection delivery be well below the surface of the water, this may be considered an ample allowance.

Vacuum. lbs. per Inch.	Velocity of Water. Feet per minute.
12·15	1714
13	1774
14	1832

In high and large condensors for marines, the injection should be led in pretty near the top; taking care, especially when the steamer is shallow, to keep the outlet at a lower level than the water surface outside; the outlet should be arranged with a rose or dashplate to scatter the water as much as possible over the whole area.

The bilge injection for marines should always be kept quite distinct from the sea injection; it should have a good large rose placed in the bilge in a convenient and attainable place, and should be led direct into the condensor by a separate pipe and cock. This is a point of great importance, for when the bilge injection is connected with the sea injection before reaching the condensor, if by any accident or mismanagement both cocks be left open, the sea water can run direct into the bilge. These sort of mistakes do occur sometimes, and cannot always be rectified till too late. By keeping the pipes entirely distinct, the possibility of accident from this source is avoided.

LOCOMOTIVE.

To find the evaporating power of a locomotive boiler.

Find the evaporating power of the boiler when burning 10 lbs. of coke per sq. foot of grate per hour, as per Rule, page 11.

Then:

Evap. thus found × No. in table corresp. to rate of combust. = Water evaporated, cub. ft. per hour.

Coke consumed. lbs. per ft. per hour.	Multiplier.	Coke consumed. lbs. per ft. per hour.	Multiplier.
20	2·	50	3·
25	2·25	60	3·1
30	2·4	70	3·2
35	2·6	80	3·3
40	2·8	95	3·4

In the higher rates of combustion there is evidently a great loss of effect, most probably from the want of sufficient time being allowed for the surface to absorb and transfer the large quantity of heat which is generated; partly, perhaps, from a portion of the fuel not wholly burned being continually abstracted from the fire, and drawn through the tubes by the force of the draught.

It must be observed that the proportion of heating surface to fire, most suitable for ordinary boilers with a natural draft, does not appear to be the best for a locomotive boiler with an artificial draft. The great quantity of heat generated requires a proportionable surface to absorb it; and there is no reason to doubt that 30 square feet of effective heating surface to 1 of fire grate gives a more economical result than 20 to 1, although with ordinary boilers 16 to 1 appears to be the outside proportion. See page 16.

TRACTION.

To find the power of traction of a locomotive engine.

$$\frac{\text{Area cyl. ins.} \times \text{average pressure on piston, lbs.} \times 2}{\text{Proportion of circumference of wheel to the double stroke}}$$

=Force applied on circum. of wheel, or on drag link, lbs.

Or simply,

$$\frac{\text{Area cyl. ins.} \times \text{average pressure on piston, lbs.} \times \text{stroke, feet}}{\text{No. in table corresponding to diameter of wheel.}}$$

=Force applied on drag link, lbs.

Diameter Wheel. Feet.	Divisor.	Diameter Wheel. Feet.	Divisor.
3·6	2·75	6·0	4·71
4·0	3·14	6·6	5·1
4·6	3·5	7·0	5·49
5·0	3·92	7 6	5·89
5·6	4·32	8·0	6·28

The above rule makes no allowance for friction, as this is taken into account in the resistance to be overcome.

RESISTANCE.

The resistance to be overcome is composed of the following:—

1st. The Friction:

That of the engine=15 lbs. per ton.

Tender and carriages= 8 „

2nd. The resistance of the air due to the speed, as per following table:—

Velocity of Wind.	Force per sq. foot.	Velocity of Wind.	Force per sq. foot.
Miles per hour.	lbs.	Miles per hour.	lbs.
10	·5	45	10
15	1	50	12·5
20	2	60	18
25	3	70	24
30	4·5	80	32
35	6	90	40
40	8	100	50

15 miles per hour is the speed of a fresh breeze of wind.

Besides the above, which may be taken as standard resistances, the force of the wind may be taken into account either for or against the engine, as it may happen ; and in some cases, *i. e.* strong side winds, very high speeds, or for badly laid rails, an extra rate for friction should be allowed.

To find the resistance or assistance at inclines.

$$\frac{\text{Weight of train. Engine and tender. lbs.}}{\text{Proportion of the incline.}} = \left\{\begin{array}{l}\text{Resistance due}\\ \text{to incline, lbs.}\end{array}\right.$$

For instance, for an inclination of 1 in 90, divide by 90.

PADDLE WHEELS.

Diameter, 3 to 5 times the stroke of engines.

3 times is a good proportion for tug boats with a good stroke, and for engines of low power in proportion to size of boat.

4 times is a good proportion for ordinary purposes ; with this proportion an engine running 250 feet per minute will drive boat 14 miles per hour.

5 times, outside size, for sharp boats of large power.

The fast running boats on the Hudson, with engines of 8 to 15 feet stroke, running very fast, and developing a great power with a light engine, use the first proportion.

On the Ohio and Mississippi, engines 6 to 10 feet stroke, the wheels generally are 4 times the stroke.

The influence of the size in affecting the performance of the engine will be seen clearly in investigating the speed of vessel. (See STEAM VESSEL.)

FLOATS.

Length, $\frac{1}{2}$ to $\frac{1}{4}$ of width of boat;

Breadth, $\frac{1}{3}$ to $\frac{1}{6}$ of depth of boat;

Diminishing in the proportions as the size of the vessel increases.

The principle being, that the total vertical area of the floats immersed should be about $\frac{1}{2}$ the immersed midship section of the vessel; $\frac{1}{3}$ the minimum; equal to it the maximum.

SLIP OF WHEELS.

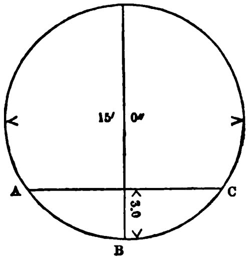
The slip will be a minimum, when the total immersed float area is equal to the vessel's immersed section; the depth of float being not more than $\frac{1}{14}$ of the diameter of the wheel, the float being immersed overhead and no more; in this case the slip will not be more than $\frac{1}{10}$.

When the total float area is made equal to $\frac{1}{2}$ the immersed midship section, which will be found a good medium, the slip will vary from $\frac{1}{6}$ to $\frac{1}{5}$, depending on the immersion. See below.

A total float surface $= \frac{1}{3}$ the mid. section may be sufficient for boats of small power and moderate speed, but this should be the minimum in any case; the slip will vary from $\frac{1}{4}$ to $\frac{1}{6}$.

To find the slip of floats as depending on the immersion, the total vertical area of floats immersed being not less than $\frac{1}{2}$ the immersed midship section of vessel.

Fig. 17.



Let A B C be the immersed circumference of wheel; A C the water line.

Then $\dfrac{(ABC - AC) \times 2}{ABC} =$ Slip for an ordinary wheel.

The fractional difference between the lengths $\times$ 2 representing the slip.

For instance; Suppose the wheel to be 15 feet diameter, immersed 3 feet.

Then the proportion of immersed circumferenee to the chord will be as $15\frac{3}{4}$ to $14\frac{1}{4}$;

The fractional difference between the two lengths is $\frac{1}{10}$, and $\frac{1}{10} \times 2 = \frac{1}{5}$ slip.

For a wheel with vibrating floats, the slip is only $\frac{1}{2}$ that of an ordinary wheel of equal immersion and area.

And $\dfrac{ABC - AC}{ABC} =$ Slip for a wheel with vibrating floats.

To find the speed of floats in miles per hour, the size of wheel and number of revolutions being ascertained.

$$\frac{\text{Mean diam. of wheel to centre of floats Ft.} \times \text{Revs. per min.}}{28} = \text{Speed of floats, miles per hour.}$$

To find the diameter necessary to maintain a given speed of floats, the number of revolutions being determined.

$$\frac{\text{Speed required, miles per hour} \times 28}{\text{Revs. per min.}} = \text{Mean diam. of wheel, feet. to centre of floats.}$$

PEDESTAL — BRACKET.

PEDESTAL.

Good proportions.

Thickness of cover	·4	of diam. of bearing.	
Ditto of sole plate	·3	„	„
Diameter of bolts	·25	„	„ if 2.
„ „	·18	„	„ if there are 4.

Distance between bolts twice diameter of bearing.

BRACKET.

Solid.	Metal round brass	= ½ diam. of bearing.
	General thickness web, &c.	= ¼ „ „
With feathers.	Width at lightest	= diam. of bearing.
	Thickness	= ⅛ „

RIVET.

See Boiler, page 18.

ROPE.

To find breaking weight of an ordinary tarred hemp rope.

$$\frac{(\text{Circumference, ins.})^2}{5} = \text{Breaking weight, tons.}$$

A rope should not be loaded with more than $\frac{1}{3}$ its breaking weight.

To find weight of rope.

$$\frac{(\text{Circum. ins.})^2 \times \text{Length, feet}}{24} = \text{Weight, lbs.}$$

Or,

$$\frac{(\text{Circum. ins.})^2}{4} = \text{Weight, lbs. per fathom.}$$

SCREW.

The table below gives the number of threads for each diameter in Whitworth's taps.

Diameter Tap.	Threads per inch.	Diameter Tap.	Threads per inch.	Diameter Tap.	Threads per inch.
$\frac{1}{4}$	20	$1\frac{1}{8}$ $1\frac{1}{4}$	7	$3\frac{1}{4}$ $3\frac{1}{2}$	$3\frac{1}{4}$
$\frac{3}{8}$	16	$1\frac{3}{8}$ $1\frac{1}{2}$	6	$3\frac{3}{4}$ 4	3
$\frac{1}{2}$	12	$1\frac{5}{8}$ $1\frac{3}{4}$	5	$4\frac{1}{4}$ $4\frac{1}{2}$	$2\frac{7}{8}$
$\frac{5}{8}$	11	$1\frac{7}{8}$ 2	$4\frac{1}{2}$	$4\frac{3}{4}$ 5	$2\frac{3}{4}$
$\frac{3}{4}$	10	$2\frac{1}{4}$ $2\frac{1}{2}$	4	$5\frac{1}{4}$ $5\frac{1}{2}$	$2\frac{5}{8}$
$\frac{7}{8}$	9	$2\frac{3}{4}$ 3	$3\frac{1}{2}$	$5\frac{3}{4}$ 6	$2\frac{1}{2}$
1	8				

In the above threads the angle used is 55°.
The depth of thread = pitch.
$\frac{1}{6}$ of the depth of thread is rounded off at top and bottom.

Square threads have half the above number of threads per inch.

SCREW PROPELLER.

Usual proportions :—

Diameter, $\frac{1}{3}$ to $\frac{1}{2}$ beam of vessel.

Pitch $\frac{4}{3}$ to $2\frac{1}{2}$ times diameter, and 8 to 12 times the stroke of engine. See below.

Length, $\frac{1}{8}$ to $\frac{1}{4}$ diameter.

As to diameter, the larger it is made the better ; the pitch can bear a better proportion to the diameter ; the slip is reduced, and the screw propels with more certainty and success in head winds.

The pitch should not exceed $1\frac{1}{2}$ times diameter where it can be avoided ; the proper proportion, however, depends principally upon the stroke of the engine, and its power in proportion to the size of vessel.

When the power is small for the vessel, and the engine is intended to run pretty fast, propelling the vessel at a moderate speed, the pitch should not be more than 8 times the stroke of engine.

If the boat is intended to go fast, and has sufficient propelling power, a proportion of 10 times the stroke will be found satisfactory ; in this case the engine running 300 feet per minute will propel the vessel fully 14 miles per hour, allowing $\frac{1}{8}$ for slip.

For ocean steamers, where there may be difficulty in keeping the engines running very fast for a continuance, and for sharp vessels with large power, 12 times the stroke may be given. Thus arranged, the engine running 220 feet per minute, will drive the vessel $12\frac{1}{2}$ miles per hour, and proportionably, allowing $\frac{1}{6}$ for slip.

If the engine is geared, the pitch × number of revolutions for 1 of engine, must be taken as effective pitch in proportioning screw to engine.

The influence of the pitch in affecting the performance of the engine will be seen clearly in investigating the speed of vessel. (See STEAM VESSEL.)

To find the effective area of any screw.

$$\frac{(\text{Diameter, feet})^2 \times \text{Length, ft.}}{\text{Pitch, ft.}} \times \cdot 7 = \text{Area of each blade.}$$

supposing the edges to be parallel, looking on the side.

As a general rule, an effective area of $\frac{1}{10}$ of the immersed midship section will be found a good proportion. For boats of light draught considerably larger if possible.

SLIP.

The slip of screw propellers varies very much; the table below will however give a rough approximation under ordinary circumstances.

Effective Area.	Pitch=Diam.	Pitch=$1\frac{1}{2}$ Diam.	Pitch=2 Diam.
$\frac{1}{9}$ of immersed section .	$\frac{1}{8}$	$\frac{1}{7}$	$\frac{1}{6}$
$\frac{1}{12}$ " .	$\frac{1}{7}$	$\frac{1}{6}$	$\frac{1}{5}$
$\frac{1}{15}$ " .	$\frac{1}{6}$	$\frac{1}{5}$	$\frac{1}{4}$

The slip will be more than this, in screws with a pitch exceeding two diameters, and in boats where the shaft is but little below the surface of the water—in some cases the slip being as much as $\frac{1}{2}$, and generally from $\frac{1}{3}$ to $\frac{1}{2}$, when the shaft is not more than 2 feet below the surface.

The slip will be less than this, when the pitch is less than the diameter, and when the screw is very deeply immersed.

To find the speed of a screw in miles per hour, the pitch and number of revolutions being ascertained.

$$\frac{\text{Pitch, ft.} \times \text{Revs per minute}}{88} = \text{Speed, miles per hour.}$$

To find the pitch necessary to maintain a given speed of screw, with a given number of revolutions.

$$\frac{\text{Speed required, miles per hour} \times 88}{\text{Revs. per minute}} = \text{Pitch, feet.}$$

A very good way of securing the screw on the shaft is that adopted by Penn; that is, a broad cross cutter through boss and shaft; the eye of the screw not being recessed, but bored straight through. The shaft is thus secured from rusting; the cutter can easily be driven back, and the screw can afterwards be loosed by appropriate cutters through the same hole with certainty and ease.

SHAFT.

CRANK SHAFT.

Wrought iron - - -	2 to $2\frac{1}{8}$ piston rod.
Cast iron - - - -	$2\frac{1}{2}$ "

To find the size of any shaft necessary to transmit a given Power.

$$\sqrt[3]{\frac{\text{Horse-Power} \times 300}{\text{Revs. per min.}}} = \text{Diameter, ins. wrought iron.}$$

The above applies to flywheel or paddlewheel shafts.

For ordinary purposes, 2nd motion shafting, &c.	200 is the proper multiplier.
Cast iron do. . . .	300 " "

For cast iron flywheel shafts, 450 is the proper multiplier.
For marines with a single engine, wrought iron shaft } 200 „ „

To find the size of bearing necessary to carry a given weight; as for water-wheels, axles, &c.

$$\sqrt[3]{\frac{\text{Weight, lbs.} \times \text{Length bearing, ins.}}{1000}} = \left\{\begin{array}{l}\text{Diam. inches}\\ \text{wrought iron.}\end{array}\right.$$

600 is divisor for cast iron.

In all the above cases, if the weight be carried at any distance from the bearings, the body of the shaft must be calculated as a beam, and proportioned accordingly.

To find the size necessary to withstand a given amount of torsion.

$$\sqrt[3]{\frac{\text{Weight, lbs.} \times \text{Leverage, ft.}}{150}} = \left\{\begin{array}{l}\text{Diam. ins. wrot. iron, equal}\\ \text{to 6 times breakg. weight.}\end{array}\right.$$

100 is the divisor for cast iron.

The weight required to twist a wrought iron shaft being:

$$\frac{(\text{Diam. ins.})^3 \times 1000}{\text{Leverage, feet}} = \text{Twisting weight.}$$

600 is multiplier for cast iron.
1700 „ steel.
450 „ copper.

SOLDERING.

The solder for joints requires to be of some metal more fusible than that of the substances to be joined.

For Copper, usual solder 6 to 8 parts brass to 1 of zinc; 1 of tin sometimes added.

A still stronger solder, 3 parts brass, 1 of zinc.

To prepare this solder.—Melt the brass in a crucible, when melted add in the zinc, and cover over for 2 or 3 minutes till the combination is effected, then pour it out, over a bundle of twigs, into a vessel of water, or into a mould composed of a number of little channels, so that the solder may be in long strips convenient for use.

Brass filings alone will answer very well.

To braze with this solder.—Scrape the surfaces perfectly clean, and secure the flange or joint carefully; cover the surfaces to be brazed with borax powder moistened; apply the solder, and melt it in with the flame of a clear coke fire from a smith's hearth; particular care being taken not to burn the copper.

Iron and brass are soldered with spelter, which is brass and zinc in equal parts; the process being performed in a manner similar to the above. For ironwork, however, sometimes rather differently; the articles are fixed in their position, and the solder applied, a covering of loam is then put over all to exclude the air, the work thus prepared is then put into the fire a sufficient time to melt the solder in.

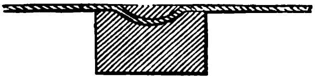
For Lead	the solder is	1 part tin,		1 to 2 of lead.	
Tin	„	1 to 2	„	1	„
Zinc	„	1	„	1 to 2	„
Pewter	„	1	„	1	„
		and 1 to 2 parts of bismuth.			

In using these the surfaces to be joined are made perfectly clean and smooth, and then covered with sal-ammoniac, or resin, or both; the solder is then applied, being melted in, and smoothed over by the soldering iron.

The joints of lead plates for some purposes are made as follows:—

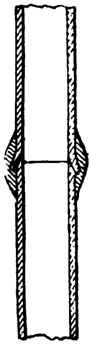
The edges are brought together, hammered down into a sort of channel cut out of wood, and secured with a few tacks. The hollow is then scraped clean with a scraper, rubbed over with candle grease, and a stream of hot lead is poured into it, the surface being afterwards smoothed with a red-hot plumber's iron.

Fig. 18.



To joint lead pipes.—Widen out the end of one pipe with a taper wood drift, and scrape it clean inside; scrape the end of the other pipe outside a little tapered, and insert it in the former: then solder it with common lead solder as before described; or if required to be strong, rub a little tallow over, and cover the joint with a ball of melted lead, holding a cloth (2 or 3 plies of greased bed-tick) on the under side; and smoothing over with it and the plumber's iron.

Fig. 19.



STEAM.

To find the pressure of steam from the temperature.

Tredgold.

$$\frac{\left(\frac{\text{Temp.}\,^\circ + 100}{177}\right)^6}{2{\cdot}04} - 14{\cdot}7 = \begin{array}{l}\text{Pressure above atmosphere,}\\ \text{lbs. per sq. inch.}\end{array}$$

To find the volume of steam from the pressure.

Tredgold.

$$\frac{(\text{Temp.}\,^\circ \text{ corresponding to pressure} + 459^\circ) + 76{\cdot}5}{\text{Pressure above atmosphere, lbs.} \times 4}$$
$$= \text{Volume of steam produced by 1 of water.}$$

For table of volumes under different pressures, see p. 55.

To find the velocity of steam of a given pressure through an orifice.

Tredgold.

$$8\sqrt{\text{Vol. of steam from 1 of water} \times \text{Pressure, lbs.} \times 2{\cdot}2}$$

$=$Velocity of steam, feet per second.

Pressure, lbs. per sq. inch.	Velocity, feet per Second.	Pressure, lbs.	Velocity, feet per Second.	Pressure, lbs.	Velocity, feet per Second.
1	482	20	1504	80	1919
2	663	30	1643	90	1936
3	791	40	1729	100	1957
4	890	50	1791	110	1972
5	973	60	1833	120	1991
10	1241	70	1872	130	2004

STEAM VESSEL.

RESISTANCE.

The resistance of, or force required to propel, any vessel, depends,

1st, and principally, upon the area of the immersed midship section, which in fact represents the body of water which requires to be moved aside to permit the passage of the vessel.

2nd. Upon the shape of the vessel, in a paddle steamer principally upon the angle of the bow; in a screw steamer the shape of the stern being also of great importance, as enabling the screw to act properly on the water.

3rd. Upon the speed at which the vessel is driven; the speed being doubled, it requires four times the force to propel it.

The friction of the water may also be something, but the resistance from this source is so small in comparison with that from the causes represented above, that practically it need not be taken into account.

In calculating the power necessary to propel, and in comparing the resistance of different vessels, it is necessary to bring each to some common point of comparison; a very convenient one being lbs. per square foot of immersed section at 10 miles per hour.

To find approximately the resistance of any vessel at 10 *miles per hour.*

Find the proportion the average water lines of the bow bear to half the beam.

Then

$$\frac{100}{\text{Prop. of aver. bow lines to the } \frac{1}{2} \text{ beam}} = \left\{ \begin{array}{l} \text{Resistance, lbs. per sq. ft. immersed} \\ \text{section, at 10 miles per hour.} \end{array} \right.$$

For instance;

Suppose A B be centre line of a vessel;

A C a line showing the average sharpness of the water lines immersed;

B C half the beam of the vessel.

Then $\frac{A\,C}{B\,C}$ gives the proportion of average water lines of bow to the $\frac{1}{2}$ beam.

If A C be 40 feet, B C 8 feet,

$$\frac{100}{\frac{A\,C}{B\,C}} = \frac{100}{5} = 20 \text{ lbs. per sq. foot resistance.}$$

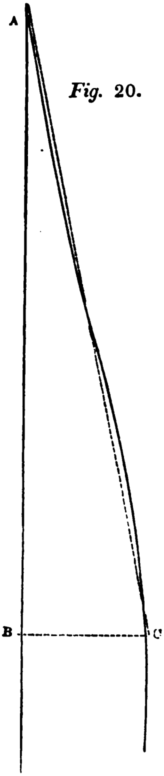


Fig. 20.

To find the resistance at any other speed.

If less than 10 miles,

$$\frac{\text{Resistance at 10 miles}}{\left(\frac{10}{\text{Speed, miles per hour}}\right)^2} = \left\{ \begin{array}{l} \text{Resistance at the lower speed,} \\ \text{lbs. per square foot of immersed} \\ \text{section.} \end{array} \right.$$

If more than 10 miles,

$$\text{Resistance at 10 miles} \times \left(\frac{\text{Speed, miles per hour}}{10}\right)^2 = \text{Resis-}$$

tance at increased speed, lbs. per sq. ft. immersed section.

The resistance at a given speed being ascertained, to reduce it to the resistance at 10 *miles per hour.*

If the speed is less than 10 miles,

$$\left(\frac{10}{\text{Speed in miles}}\right)^2 \times \text{Given resistance} = \text{Resistance at 10}$$

miles per hour, lbs. per sq. foot, immersed section.

If more than 10 miles,

$$\frac{\text{Given resistance}}{\left(\frac{\text{Speed}}{10}\right)^2} = \left\{\begin{array}{l}\text{Resistance at 10 miles per hour, lbs.} \\ \text{per sq. foot, immersed section.}\end{array}\right.$$

PROPELLING FORCE.

The force a given engine is able to apply in propelling a steam-vessel depends:

1st. On the pressure on the piston, minus the friction due to the size and form of engine.

2nd. On the speed of the advance of screw or float as compared with the speed of the piston.

3rd. On the slip of the screw or float.

The pressure on the piston, if not found by indicator diagram, can be ascertained approximately, by calculating the evaporative power of the boiler (see p. 12); by then finding how full this supply of steam will fill the cylinders, the number of strokes being known. For Table of Friction, see p. 38.

The speed of advance of float or screw as compared to that of piston is simply as follows:

For paddle-wheels.

$$\frac{\text{Circum. at centre of float, ft.}}{\text{Twice stroke of engine, ft.}} = \text{Prop. speed of float to engine.}$$

For direct acting screws.

$$\frac{\text{Pitch of screw, ft.}}{\text{Twice stroke of engine, ft.}} = \text{Prop. speed of screw to engine.}$$

For geared screws.

$$\frac{\text{Pitch of screw} \times \text{No. of rev. to 1 of engine}}{\text{Twice stroke of engine, ft.}} = \left\{\begin{array}{l}\text{Prop. speed of} \\ \text{screw to engine.}\end{array}\right.$$

For the slip of paddle-wheel, or screw, see pages 64, 69.

To find the force a given pair of engines are able to apply in propelling a vessel.

$$\frac{\text{Area cyls. ins.} \times (\text{Average pressure} - \text{friction lbs.})}{\text{Prop. speed of float or screw to double stroke}} - \text{Slip, lbs.}$$
$= \text{Force applied to immersed mid. section, lbs.}$

Suppose the force applied by the engine to the float or screw be 10,000 lbs.

And the slip be taken at $\frac{1}{5}$,

The actual force applied to the immersed mid. section will be $10{,}000 - 2000 = 8000$ lbs.

and $\frac{\text{Force applied to imm. mid. section, lbs.}}{\text{Area immersed section, sq. ft.}} = \text{Force applied}$ to immersed section, lbs. per sq. ft.

Finally, to find the speed at which a given engine will propel a given vessel.

1st. Find the force the engines are able to apply, as per rule above.

2nd. Find the resistance of vessel at 10 miles per hour, as per rule, page 75.

3rd. Find the speed at which the resistance of the vessel is equal to the force the engines are able to apply at that speed; and this will be the outside speed attainable in smooth water, and with no wind, the vessel being of good shape and proportions.

STRENGTH OF MATERIALS.

	Cohesive Force, Tons per sq. in.	Crushing Force, Tons per sq. in.
Metals.		
Brass	8	4·5
Copper, cast	8·5	
„ wrought	15	
Gun metal	16	
Iron, cast	8	49
„ bar, English	25	20
„ boiler plate	20	16
Lead	·8	
Steel	55	
Tin	2	
Timber.		
Ash	7	4
Beech	5	4
Cedar	3	2
Elm	4·5	4·5
Fir, Scotch	3	2·5
„ Riga	4	2·5
Larch	. . .	2
Mahogany, Honduras	5	3
„ Spanish	3	3
Oak, English	5	4
Pine, pitch	4·5	2
„ yellow	5	2
Poplar	2·5	2
Teak	6	5
Stone.		
Brickwork	. . .	30
Sandstone	. . .	120
Limestone	. . .	450
Granite, Aberdeen	. . .	540

Rules for Columns and Pillars, see page 30.

TEMPERING.

The article after being completed, is hardened by being heated gradually to a bright red, and then plunged into cold water; it is then tempered by being warmed gradually and equably, either over a fire, or on a piece of heated metal till of the colour corresponding to the purpose for which it is required, as per table below, when it is again plunged into the water.

	Corresponding Temperature.		
A very pale straw	430°	Lancets, Razors	
Straw	450°		
Darker straw	470°	Penknives, Scissors	All kinds of wood tools. Screw taps.
Yellow	490°		
Brown yellow	500°	Hatchets, Chipping chisels, Saws. All kinds of percussive tools.	
Slightly tinged purple	520°		
Purple	530°		
Dark purple	550°	Springs.	
Blue	570°		
Dark blue	600°	Soft for saws.	

To temper by the thermometer.

Put the articles to be tempered into a vessel containing a sufficient quantity to cover them,

of Oil or Tallow;

Sand;

or a mixture of 8 parts bismuth, 5 of lead, and 3 of tin, the whole to be brought up to, and kept up at the heat corresponding to the hardness required, by means of a suitable thermometer, till heated equally throughout; the articles are then withdrawn and plunged into cold water.

If no thermometer is available, it may be observed that oil or tallow begins to smoke at 430° or straw colour, and that it takes fire on a light being presented, and goes out when the light is withdrawn, at 570° or blue.

WATER.

A cubic foot	= 6·232 gallons.
"	= 62·5 lbs.
A gallon	= 10 lbs.
1 cwt.	= 1·8 cub. ft. = 11·2 gallons.
1 ton	= 35·84 " = 224 "

A column 1 inch square, 1 foot high = ·434 lbs.
" 1 " diam. " = ·341 lbs.

Centre of pressure is at $\frac{2}{3}$ depth from surface.

To find the quantity of water that will be discharged through an orifice, or pipe, in the side or bottom of a vessel.

$$\text{Area of orifice, sq. in.} \times \left\{\begin{array}{l}\text{No. corresp. to height of surface}\\ \quad\text{above orifice, as per table}\end{array}\right.$$

= Cubic feet discharged per minute.

To find the size of hole necessary to discharge a given quantity of water under a given head.

$$\frac{\text{Cubic ft. water discharged}}{\text{No. corresp. to height, as per table}} = \text{Area of orifice, sq. ins.}$$

To find the height necessary to discharge a given quantity through a given orifice.

$$\frac{\text{Cub. ft. water discharged}}{\text{Area orifice, sq. ins.}} = \text{No. corresp. to height, as per table.}$$

Height of Surface above Orifice.	Multiplier.	Height of Surface above Orifice.	Multiplier.	Height of Surface above Orifice.	Multiplier.
Ft.		Ft.		Ft.	
1	2·25	18	9·5	40	14·2
2	3·2	20	10·	45	15·1
4	4·5	22	10·5	50	16·
6	5·44	24	11·	60	17·4
8	6·4	26	11·5	70	18·8
10	7·1	28	12·	80	20·1
12	7·8	30	12·3	90	21·3
14	8·4	32	12·7	100	22·5
16	9·	35	13·3		

The velocity of water issuing from an orifice in the side or bottom of a vessel being ascertained to be as follows:—

$$\sqrt{\text{Height ft. surface above orifice}} \times 5{\cdot}4 = \left\{\begin{array}{l}\text{Velocity of water,}\\ \text{ft. per second.}\end{array}\right.$$

$$\sqrt{\text{Height ft.}} \times \text{Area orifice, ft.} \times 324 = \left\{\begin{array}{c}\text{Cubic ft. discharged}\\ \text{per minute.}\end{array}\right.$$

$$\sqrt{\text{Height ft.}} \times \text{Area orifice, ins.} \times 2{\cdot}2 = \quad \text{Do.} \quad \text{do.}$$

It may be observed, that the above rules represent the actual quantities that will be delivered through a hole cut in the plate; if a short pipe be attached, the quantity will be increased, the greatest delivery with a straight pipe being attained with a length equal to 4 diameters, and being $\frac{1}{3}$ more than the delivery through the plain hole; the quantity gradually decreasing as the length of pipe is increased, till, with a length = 60 diameters the discharge again equals the discharge through the plain orifice. If a taper pipe be attached the delivery will be still greater, being $1\frac{1}{2}$ times the delivery through the plain orifice; and it is probable that if a pipe with curved decreasing taper were to be tried, the delivery through it would be equal to the theoretical discharge, which is about 1·65 the actual discharge through a plain hole.

To find the quantity of water that will run through any orifice, the top of which is level with the surface of water as over a sluice or dam.

$$\sqrt{\begin{matrix}\text{Height, ft. from water surface to}\\ \text{bottom of orifice or top of dam}\end{matrix}} \times \left\{\begin{matrix}\text{Area of water passage,}\\ \text{sq. feet.}\end{matrix}\right\} \times 216$$

=Cub. ft. discharged per minute.

Or,

$\frac{2}{3}$ Area of water passage, sq. ins. × No. corresp. to height as per table.

=Cub. ft. discharged per minute.

To find the time in which a vessel will empty itself through a given orifice.

$$\frac{\sqrt{\text{Height ft. surface above orifice}} \times \text{Area water surface, sq. ins.}}{\text{Area orifice, sq. in.} \times 3{\cdot}7}$$

=Time required, seconds.

The above rules are founded on Bank's experiments.

WATER WHEEL.

Undershot wheels are used when the fall of water does not exceed $4\frac{1}{2}$ feet.

Speed of rim = $\frac{1}{2}$ the velocity of the water.

Power given out, ·3 to ·4 of the Horse Power of the water.

Poncelet's wheels, with curved floats, speed 8 to 10 ft. per second, developing ·5 of the Horse Power of the water.

BREAST WHEEL.

Diameter of wheel about twice the height of fall.

Speed of rim about 6 feet per second.

Power given out ·6 of the Horse Power of the water.

HIGH BREAST WHEEL.

Diameter of wheel $1\frac{1}{2}$ times height of fall.

Speed of rim about 5 feet per second.

Power given out ·66 of the Horse Power of the water.

OVERSHOT WHEEL.

Diameter of wheel 1 to $1\frac{1}{3}$ the height of fall.

Speed of rim 4 to 5 feet per second.

Power given out ·75 of the Horse Power of the water.

To find the effective Horse Power of any wheel.

$$\frac{\text{Water expended per second, cub. ft.} \times \text{Effective height of fall, ft.}}{11{\cdot}7}$$
= Horse Power of Overshot wheels.

13·3	is divisor for	High breast	wheels.
14·6	„	Breast	„
20	„	Undershot	„

The effective height of fall being the vertical distance from the point where the water reaches the wheel to the surface of the tail water, $+\frac{1}{3}$ the height from the sluice to the wheel, if the water is arranged to drop upon the wheel.

To find the quantity of water a given stream is capable of supplying, the velocity of the surface being ascertained with a float.

Area of channel, sq. ft. × Surface velocity, ft. per sec. × ·8 = Water supplied, cub. ft. per second.

To find the velocity of a stream from the inclination of the channel.

Eytelwein.

Let d = the mean hydraulic depth of the stream, *i. e.* the depth where it has an equal sectional area above and below.

Then

$\sqrt{d \times \text{Fall, ft. per mile}} \times \cdot 94 =$ Mean velocity, miles per hour.

And

$\sqrt{d \times \text{Fall, ft. per mile}} \times 82 \cdot 5 =$ Mean velocity, ft. per min.

The velocity being thus found,

Sectional area of stream, sq. ft. × Velocity ft. per min. = Water supplied, cub. ft. per min.

The water should be arranged to come upon the wheel with a velocity somewhat greater than that of the circumference of the wheel.

In the overshot wheel, the water being kept at a sufficient head above the sluice to give it this velocity, or else being allowed to drop a short distance upon the wheel; this distance, however, should not exceed the height necessary to give the required velocity, as the force thus developed is not more than $\frac{1}{3}$ of that which is developed from the weight of the same water acting upon the wheel.

In other cases, the bottom of the canal is inclined on approaching the wheel, in order to give the water the required velocity.

Buckets, 2 at least for every foot in diameter.

Shrouds, usually 1′ 0″ to 1′ 9″ wide.

Gudgeon, see SHAFT, page 70.

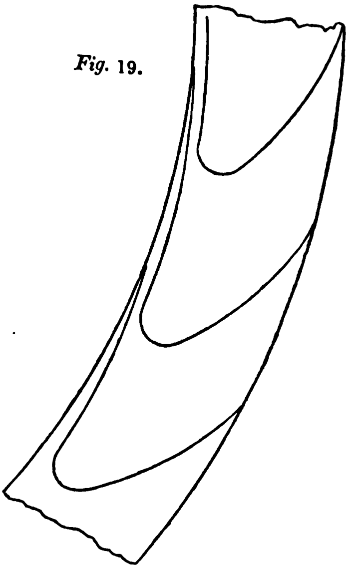
VENTILATION OF WATER WHEELS.

A very important point in the construction of water wheels is the ventilation. If this is not attended to, the water can neither fill nor leave the buckets readily, and the

wheel is consequently unable to develop so much power as it would do otherwise.

The best way of all to ventilate effectually, probably would be to do away with the sole plate altogether, carrying the back of each bucket well up behind the bucket above, leaving a clear space between, as per sketch; in this case, the back of each bucket should be nearly level with the front at the time the water enters upon the bucket.

Fig. 19.



Thus arranged, the air is enabled to get out and in with the greatest freedom, both when the water comes on the wheel and when the buckets are leaving the water.

If not otherwise arranged, a few holes should be made in the bottom of each bucket for ventilation.

GOVERNOR FOR WATER WHEELS.

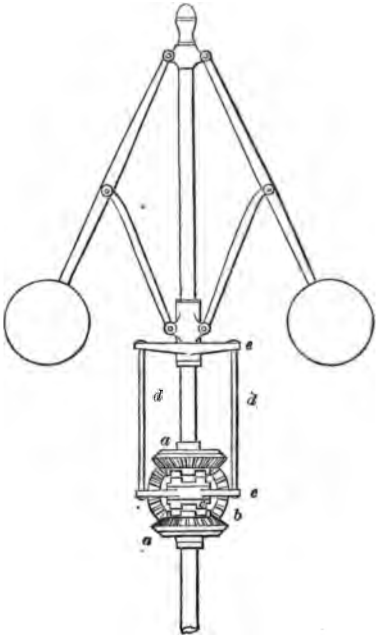
A simple and effective governor for water wheels is represented in the annexed sketch.

a a are two mitre wheels running loose on the governor spindle, working into the wheel *b*, which drives a shaft, which by means of a train of wheels or a screw, lowers or raises the sluice according to the way in which it is turned; on the faces of these two wheels are clutches.

c is a catch box turning with the spindle on a feather, and connected to the governor above by two rods *d d*, and cross bars *e e*, which are prevented from turning round by a guide on one of the rods attached to any convenient place.

When the speed is too slow, the governor falls and puts the catch in gear with the lower wheel, which is arranged

Fig. 20.



so as to open the sluice, and to give more water to the wheel. When the right speed is reached, the catch is lifted out of gear by the governor, and the sluice remains stationary at that point. On the other hand, if the speed is too great, the governor puts the upper wheel in gear, and the sluice is lowered until the proper speed is reached, when the catch is put out of gear in the same manner as before.

WEIGHT.

To find the weight of any casting.

$$\frac{\text{Width in } \tfrac{1}{4} \text{ ins.} \times \text{Thickness in } \tfrac{1}{8} \text{ ins. or vice versa.}}{10} \times \text{Length, ft.} = \left\{ \begin{array}{l} \text{Weight, lbs.} \\ \text{cast iron.} \end{array} \right.$$

For instance; to find the weight of a casting $3\tfrac{1}{4}'' \times 1\tfrac{1}{8}'' \times 2'\ 6''$ long.

$$\frac{13 \times 9}{10} = 11{\cdot}7 \times 2{\cdot}5 = 29{\cdot}25 \text{ lbs.}$$

This rule is very useful, and can easily be remembered in the following form.

$$\left.\begin{array}{c} \text{Width in } \tfrac{1}{4} \text{ ins.} \times \text{Thickness in } \tfrac{1}{8} \text{ ins.} \\ \text{or vice versa} \end{array}\right\} \begin{array}{c} \text{Cut off 1 fig. for} \\ \text{decimal,} \end{array}$$

result is lbs. per foot of length.

For Wrought Iron	add	$\frac{1}{20}$	to the result.
Lead	„	$\frac{1}{2}$	„
Brass	„	$\frac{1}{7}$	„
Copper	„	$\frac{1}{6}$	„

To find the weight from the areas.

Area, sq. ins. $\times$ Length, ft. $\times 3\tfrac{1}{7}$ = Weight, lbs. cast iron.

Multiplier for	Cast iron	3·156	or $3\frac{1}{7}$.
„	Wrought iron	3·312	„ $3\frac{1}{3}$.
„	Lead	4·854	
„	Brass	3·644	
„	Copper	3·87	

Or, Area, sq. ins. $\times$ 10 = lbs. per yard for wrought iron.

To find the weight in cwts.

$$\frac{\text{Area, sq. ins.} \times \text{Length, ft.}}{31{\cdot}9} = \text{Weight, cwts. cast iron.}$$

For wrought iron, divide by 33·6.

WEIGHT OF BOILER PLATES.

Thickness, ins.	$\frac{1}{16}$	$\frac{1}{8}$	$\frac{3}{16}$	$\frac{1}{4}$	$\frac{5}{16}$	$\frac{3}{8}$	$\frac{7}{16}$	$\frac{1}{2}$	$\frac{5}{8}$	$\frac{3}{4}$	$\frac{7}{8}$	1
Weight, lbs. per sq. foot . .	2·5	5	7·5	10	12·5	15	17·5	20	25	30	35	40

For cast iron deduct $\frac{1}{20}$.

To find weight of boiler plates in cwts.

$$\frac{\text{Area sq. ft.}}{\text{No. corresponding to thickness in table below.}} = \text{Weight, cwts.}$$

Thickness.	Divisor.	Thickness.	Divisor.	Thickness.	Divisor.
In.		In.		In.	
$\frac{1}{8}$	22·4	$\frac{3}{8}$	7·5	$\frac{5}{8}$	4·48
$\frac{3}{16}$	15·	$\frac{7}{16}$	6·3	$\frac{3}{4}$	3·73
$\frac{1}{4}$	11·2	$\frac{1}{2}$	5·6	$\frac{7}{8}$	3·2
$\frac{5}{16}$	9·	$\frac{9}{16}$	5·	1	2·8

WEIGHT OF MATERIALS.

	Lbs. per Cub. ft.	Cub. ft. per Ton.	Cub. in. per lb.
Metals:			
Brass	524	4·3	3·3
Copper, cast	549	4·08	3·147
„ wrought	557	4·02	3·1
Gun metal	549	4·08	3·147
Iron, cast	454	4·93	3·8
„ wrought	485	4·62	3·56
Lead	709	3·15	2·43
Steel	490	4·6	3·52
Tin	456	4·9	3·78
Zinc	439	5	3·93
Miscellaneous:			
Brick	120	18·7	
Chalk	174	12·8	
Clay	125	18	
Coal, see Boilers	80	28	
Cork	15	149·3	
Earth	110	20	
Glass	180	12·44	
Mercury	848	2·64	
Oil, olive	57	39·3	
Sand	95	23·56	
Slate	167	13·4	
Water, fresh	62·5	35·8	
„ sea	64·5	34·8	
White lead	198	11·3	

	Lbs. per Cub. ft.	Cub. ft. per Ton.
Stone:		
Granite	165	13·5
Limestone	165	13·5
Marble	171	13·1
Paving stone	151	14·8
Portland „	160	14
Sandstone	130	17
Timber:		
Ash	48	46
Beech	46	48·7
Cedar	35	64
Elm	44	51
Fir, Riga	30	74
„ Memel	34	66
Larch	33	68
Mahog. Spanish	57	39·3
Oak, English	52	43
„ African	59	38
Pine, pitch	43	51·6
„ red	41	54·6
„ yellow	38	59
„ white	34	66
Poplar	33	68
Teak	46	48·7

WHEEL.

To find size of teeth necessary to transmit a given H.P.

Tredgold.

$$\frac{\text{Horse Power} \times 240}{\text{Diameter of wheel, ft.} \times \text{Revs. per min.}} = \text{Strength of tooth.}$$

$$\sqrt{\frac{\text{Strength}}{\text{Breadth, ins.}}} = \text{Pitch, ins.} \qquad \frac{\text{Strength}}{(\text{Pitch, ins.})^2} = \text{Breadth, ins.}$$

The above rule will be found very suitable for a speed of circumference of about 240 feet per minute. For speeds above, add to 240 half the difference, for speeds below, deduct half the difference, between 240 and the actual speed, the result being a suitable multiplier.

For instance; at 300 ft. per min., 60 being the difference, $240 + 30 = 270$ multiplier.

At 160 ft. per min., 80 being the difference, $240 - 40 = 200$ multiplier.

The reason being, that with higher speeds, the friction, wear, and liability to shocks is increased, at lower speeds decreased, and the teeth may advantageously be proportioned accordingly.

To find the Horse Power that any wheel will transmit.

$$\frac{(\text{Pitch, ins.})^2 \times \text{Breadth, ins.} \times \text{Diam. ft.} \times \text{Revs. per min.}}{\text{Appropriate No. according to speed, as above.}}$$
$= \text{Horse Power.}$

To find the multiplying number for any wheel.

$$\frac{(\text{Pitch, ins.})^2 \times \text{Breadth, ins.} \times \text{Diam. ft.} \times \text{Revs. per min.}}{\text{Horse Power}}$$
$= \text{Multiplying No. as above.}$

To find the size of teeth to carry a given load in lbs.

$$\frac{\text{Load, lbs.}}{1120} = \text{Breaking strength of teeth.}$$

$$\frac{\text{Load, lbs.}}{280} = \left\{ \begin{array}{l} \text{Strength for very low speeds, and for steady} \\ \text{work; being 4 times the breaking strength.} \end{array} \right.$$

$$\frac{\text{Load, lbs.}}{140} = \left\{ \begin{array}{l} \text{Strength for ordinary purposes of machinery;} \\ \text{being 8 times the breaking strength.} \end{array} \right.$$

$$\frac{\text{Load, lbs.}}{100} = \left\{ \begin{array}{l} \text{Strength for high speeds, and irregular work;} \\ \text{or when the teeth are exposed to shocks.} \end{array} \right.$$

As before,

$$\frac{\text{Strength}}{(\text{Pitch, ins.})^2} = \text{Breadth, ins.} \qquad \sqrt{\frac{\text{Strength}}{\text{Breadth, ins.}}} = \text{Pitch, ins.}$$

PROPORTIONS FOR WHEELS.

Length of tooth, $\frac{3}{4}$ of pitch.

Clearance of tooth, $\frac{1}{16}$ inch for every inch of pitch.

Breadth of face, $2\frac{1}{2}$ pitch is a good proportion.

Rim and flat arms equal in thickness to the teeth.

Breadth of flat arms, $1\frac{1}{4}$ to $1\frac{1}{2}$ pitch, depending on their number, increasing in width towards the centre, $\frac{1}{2}$ inch per foot.

Feathers, thickness, ·3 of pitch.

Boss, thickness, $\frac{1}{2}$ diam. of bore for moderate depths, and when the shaft is proportioned to the wheel: if the shaft is larger, ·8 of pitch is a proper proportion.

TABLE OF DECIMAL PARTS.

Inch.	Decimal of an Inch.
$\frac{1}{32}$	·03125
$\frac{1}{16}$	·0625
$\frac{3}{32}$	·09375
$\frac{1}{8}$	·125
$\frac{1}{16}$	·1875
$\frac{1}{4}$	·25
$\frac{1}{16}$	·3125
$\frac{3}{8}$	·375
$\frac{1}{16}$	·4375
$\frac{1}{2}$	·5
$\frac{1}{16}$	·5625
$\frac{5}{8}$	·625
$\frac{1}{16}$	·6875
$\frac{3}{4}$	·75
$\frac{1}{16}$	·8125
$\frac{7}{8}$	·875
$\frac{1}{16}$	·9375

The intermediate $\frac{1}{32}$ may be found by adding in ·03125.

Ins.	Decimal of a Foot.
$\frac{1}{16}$	·0052
$\frac{1}{8}$	·01041
$\frac{1}{4}$	·02083
$\frac{3}{8}$	·03125
$\frac{1}{2}$	·04166
$\frac{5}{8}$	·0528
$\frac{3}{4}$	·0625
$\frac{7}{8}$	·0729
1	·0833
2	·1666
3	·25
4	·3333
5	·4166
6	·5
7	·5833
8	·6666
9	·75
10	·8333
11	·9166

For instance; to find what decimal of a foot $9\frac{7}{8}\frac{1}{16}$ is.

$$
\begin{aligned}
9 &= \cdot 75 \\
\tfrac{7}{8} &= \cdot 0729 \\
\tfrac{1}{16} &= \cdot 0052 \\
\hline
9\tfrac{7}{8}\tfrac{1}{16} &= \cdot 8281
\end{aligned}
$$

TABLE OF AREAS.

Dia. Ins.	Area, Feet.	Dia. Ins.	Area, Feet.
¼	·00034	6¼	·213
½	·00136	½	·2304
¾	·00306	¾	·2457
1	·0054	7	·2672
¼	·0085	¼	·2867
½	·0123	½	·3068
¾	·0167	¾	·3276
2	·0218	8	·3497
¼	·0276	¼	·3712
½	·0341	½	·3941
¾	·0412	¾	·4176
3	·0491	9	·4418
¼	·0576	¼	·4666
½	·0668	½	·4922
¾	·0767	¾	·5185
4	·0873	10	·5454
¼	·0985	¼	·573
½	·1104	½	·6013
¾	·123	¾	·6303
5	·1363	11	·6599
¼	·1503	¼	·6903
½	·1649	½	·7213
¾	·1803	¾	·753
6	·1963	12	·7854

TABLE OF AREAS.

Diam.	Area.	Diam.	Area.	Diam.	Area.
$\frac{1}{32}$	·00076	$2\frac{1}{2}$	4·9	$6\frac{1}{4}$	30·68
$\frac{1}{16}$	·00305	$\frac{5}{8}$	5·4119	$\frac{3}{8}$	31·918
$\frac{1}{8}$	·0122	$\frac{3}{4}$	5·9395	$\frac{1}{2}$	33·183
$\frac{1}{16}$	·0276	$\frac{7}{8}$	6·4918	$\frac{5}{8}$	34·472
$\frac{1}{4}$	·049	3	7·0686	$\frac{3}{4}$	35·785
$\frac{1}{16}$	·0769	$\frac{1}{8}$	7·6699	$\frac{7}{8}$	37·122
$\frac{3}{8}$	·1104	$\frac{1}{4}$	8·2957	7	38·485
$\frac{1}{16}$	·1503	$\frac{3}{8}$	8·9462	$\frac{1}{8}$	39·871
$\frac{1}{2}$	·1963	$\frac{1}{2}$	9·6211	$\frac{1}{4}$	41·282
$\frac{1}{16}$	·2485	$\frac{5}{8}$	10·321	$\frac{3}{8}$	42·718
$\frac{5}{8}$	·3068	$\frac{3}{4}$	11·045	$\frac{1}{2}$	44·179
$\frac{1}{16}$	·3714	$\frac{7}{8}$	11·793	$\frac{5}{8}$	45·663
$\frac{3}{4}$	·4417	4	12·566	$\frac{3}{4}$	47·173
$\frac{1}{16}$	·5185	$\frac{1}{8}$	13·364		48·707
$\frac{7}{8}$	·6013	$\frac{1}{4}$	14·186	8	50·265
$\frac{1}{16}$	·69	$\frac{3}{8}$	15·033	$\frac{1}{8}$	51·849
1	·7854	$\frac{1}{2}$	15·9	$\frac{1}{4}$	53·456
$\frac{1}{16}$	·8366	$\frac{5}{8}$	16·8	$\frac{3}{8}$	55·088
$\frac{1}{8}$	·994	$\frac{3}{4}$	17·72	$\frac{1}{2}$	56·745
$\frac{3}{16}$	1·1075	$\frac{7}{8}$	18·665	$\frac{5}{8}$	58·426
$\frac{1}{4}$	1·2271	5	19·635	$\frac{3}{4}$	60·132
$\frac{3}{8}$	1·4848	$\frac{1}{8}$	20·629	$\frac{7}{8}$	61·862
$\frac{1}{2}$	1·7671	$\frac{1}{4}$	21·647	9	63·617
$\frac{5}{8}$	2·0739	$\frac{3}{8}$	22·691	$\frac{1}{8}$	65·397
$\frac{3}{4}$	2·4	$\frac{1}{2}$	23·758	$\frac{1}{4}$	67·201
$\frac{7}{8}$	2·7611	$\frac{5}{8}$	24·85	$\frac{3}{8}$	69·029
2	3·1416	$\frac{3}{4}$	25·967	$\frac{1}{2}$	70·882
$\frac{1}{8}$	3·5465	$\frac{7}{8}$	27·108	$\frac{5}{8}$	72·76
$\frac{1}{4}$	3·976	6	28·274	$\frac{3}{4}$	74·662
$\frac{3}{8}$	4·43	$\frac{1}{8}$	29·465	$\frac{7}{8}$	76·589

Diam.	Area.	Diam.	Area.	Diam.	Area.
10	78·54	$16\frac{3}{4}$	220·35	$25\frac{1}{2}$	510·7
$\frac{1}{8}$	80·516	17	226·98	$\frac{3}{4}$	520·77
$\frac{1}{4}$	82·516	$\frac{1}{4}$	233·70	26	530·93
$\frac{3}{8}$	84·541	$\frac{1}{2}$	240·53	$\frac{1}{4}$	541·19
$\frac{1}{2}$	86·59	$\frac{3}{4}$	247·45	$\frac{1}{2}$	551·55
$\frac{5}{8}$	88·664	18	254·47	$\frac{3}{4}$	562·
$\frac{3}{4}$	90·763	$\frac{1}{4}$	261·59	27	572·55
$\frac{7}{8}$	92·886	$\frac{1}{2}$	268·8	$\frac{1}{4}$	583·21
11	95·033	$\frac{3}{4}$	276·12	$\frac{1}{2}$	593·96
$\frac{1}{8}$	97·205	19	283·53	$\frac{3}{4}$	604·81
$\frac{1}{4}$	99·402	$\frac{1}{4}$	291·06	28	615·75
$\frac{3}{8}$	101·62	$\frac{1}{2}$	298·65	$\frac{1}{4}$	626·79
$\frac{1}{2}$	103·87	$\frac{3}{4}$	306·35	$\frac{1}{2}$	637·94
$\frac{5}{8}$	106·14	20	314·16	$\frac{3}{4}$	649·18
$\frac{3}{4}$	108·43	$\frac{1}{4}$	322·06	29	660·52
$\frac{7}{8}$	110·75	$\frac{1}{2}$	330·06	$\frac{1}{4}$	671·96
12	113·1	$\frac{3}{4}$	338·16	$\frac{1}{2}$	683·49
$\frac{1}{4}$	117·86	21	346·36	$\frac{3}{4}$	695·13
$\frac{1}{2}$	122·72	$\frac{1}{4}$	354·66	30	706·86
$\frac{3}{4}$	127·68	$\frac{1}{2}$	363·05	$\frac{1}{4}$	718·69
13	132·73	$\frac{3}{4}$	371·54	$\frac{1}{2}$	730·62
$\frac{1}{4}$	137·89	22	380·13	$\frac{3}{4}$	742·64
$\frac{1}{2}$	143·14	$\frac{1}{4}$	388·82	31	754·77
$\frac{3}{4}$	148·49	$\frac{1}{2}$	397·61	$\frac{1}{4}$	766·99
14	153·94	$\frac{3}{4}$	406·49	$\frac{1}{2}$	779·31
$\frac{1}{4}$	159·48	23	415·47	$\frac{3}{4}$	791·73
$\frac{1}{2}$	165·13	$\frac{1}{4}$	424·56	32	804·25
$\frac{3}{4}$	170·87	$\frac{1}{2}$	433·74	$\frac{1}{4}$	816·86
15	176·71	$\frac{3}{4}$	443·01	$\frac{1}{2}$	829·58
$\frac{1}{4}$	182·65	24	452·39	$\frac{3}{4}$	842·39
$\frac{1}{2}$	188·69	$\frac{1}{4}$	461·86	33	855·3
$\frac{3}{4}$	194·83	$\frac{1}{2}$	471·43	$\frac{1}{4}$	868·31
16	201·06	$\frac{3}{4}$	481·1	$\frac{1}{2}$	881·41
$\frac{1}{4}$	207·39	25	490·87	$\frac{3}{4}$	894·62
$\frac{1}{2}$	213·82	$\frac{1}{4}$	500·74	34	907·92

Diam.	Area.	Diam.	Area.	Diam.	Area.
34¼	921·32	43	1452·2	51¾	2103·34
½	934·82	¼	1469·14	52	2123·72
¾	948·42	½	1486·17	¼	2144·19
35	962·11	¾	1503·3	½	2164·75
¼	975·91	44	1520·53	¾	2185·42
½	989·8	¼	1537·86	53	2206·18
¾	1003·79	½	1555·28	¼	2227·04
36	1017·88	¾	1572·81	½	2248·01
¼	1032·06	45	1590·43	¾	2269·06
½	1046·35	¼	1608·15	54	2290·22
¾	1060·73	½	1625·97	¼	2311·48
37	1075·21	¾	1643·89	½	2332·83
¼	1089·79	46	1661·9	¾	2354·28
½	1104·47	¼	1680·02	55	2375·83
¾	1119·24	½	1698·23	¼	2397·48
38	1134·11	¾	1716·54	½	2419·22
¼	1149·09	47	1734·94	¾	2441·07
½	1164·16	¼	1753·45	56	2463·01
¾	1179·32	½	1772·05	¼	2485·05
39	1194·59	¾	1790·76	½	2507·19
¼	1209·95	48	1809·56	¾	2529·42
½	1225·42	¼	1828·46	57	2551·76
¾	1240·98	½	1847·45	¼	2574·19
40	1256·64	¾	1866·58	½	2596·72
¼	1272·39	49	1885·74	¾	2619·35
½	1288·25	¼	1905·03	58	2642·08
¾	1304·2	½	1924·42	¼	2664·9
41	1320·25	¾	1943·91	½	2687·83
¼	1336·4	50	1963·49	¾	2710·85
½	1352·65	¼	1983·18	59	2733·97
¾	1369·	½	2002·96	¼	2757·19
42	1385·44	¾	2022·84	½	2780·51
¼	1401·98	51	2042·82	¾	2803·92
½	1418·62	¼	2062·9	60	2827·43
¾	1435·36	½	2083·07	¼	2851·04

Diam.	Area.	Diam.	Area.	Diam.	Area.
60½	2874·75	69¼	3766·43	78	4778·36
¾	2898·96	½	3793·67	¼	4809·04
61	2922·47	¾	3821·01	½	4839·82
¼	2946·47	70	3848·45	¾	4870·69
½	2970·57	¼	3875·99	79	4901·67
¾	2994·77	½	3903·62	¼	4932·74
62	3019·07	¾	3931·36	½	4963·91
¼	3043·47	71	3959·19	¾	4995·18
½	3067·96	¼	3987·12	80	5026·55
¾	3092·55	½	4015·15	¼	5058·01
63	3117·24	¾	4043·28	½	5089·58
¼	3142·03	72	4071·5	¾	5121·24
½	3166·92	¼	4099·83	81	5153
¾	3191·91	½	4128·25	¼	5184·85
64	3216·99	¾	4156·77	½	5216·81
¼	3242·17	73	4185·39	¾	5248·86
½	3267·45	¼	4214·1	82	5281·02
¾	3292·83	½	4242·92	¼	5313·27
65	3318·31	¾	4271·83	½	5345·62
¼	3343·88	74	4300·84	¾	5378·06
½	3369·55	¼	4329·95	83	5410·61
¾	3395·32	½	4359·16	¼	5443·25
66	3421·19	¾	4388·46	½	5475·99
¼	3447·16	75	4417·86	¾	5508·83
½	3473·23	¼	4447·37	84	5541·77
¾	3499·39	½	4476·9	¼	5574·8
67	3525·65	¾	4506·66	½	5607·94
¼	3552·01	76	4536·46	¾	5641·17
½	3578·47	¼	4566·35	85	5674·5
¾	3605·03	½	4596·35	¼	5707·93
68	3631·68	¾	4626·44	½	5741·46
¼	3658·43	77	4656·63	¾	5778·08
½	3685·28	¼	4686·91	86	5808·8
¾	3712·23	½	4717·3	¼	5842·63
69	3739·28	¾	4747·78	½	5876·54

Diam.	Area.	Diam.	Area.	Diam.	Area.
86¾	5910·56	93	6792·91	99¼	7736·61
87	5944·68	¼	6829·48	½	7775·64
¼	5978·89	½	6866·15	¾	7814·76
½	6013·2	¾	6902·91	100	7853·98
¾	6047·61	94	6939·78	101	8011·85
88	6082·12	¼	6976·74	102	8171·28
¼	6116·73	½	7013·8	103	8332·29
½	6151·43	¾	7050·96	104	8494·87
¾	6186·24	95	7088·22	105	8659·01
89	6221·14	¼	7125·58	106	8824·73
¼	6256·14	½	7163·03	107	8992·02
½	6291·23	¾	7200·58	108	9160·88
¾	6326·43	96	7238·23	109	9331·31
90	6361·72	¼	7275·98	110	9503·32
¼	6397·12	½	7313·82	111	9676·89
½	6432·61	¾	7351·77	112	9852·03
¾	6468·19	97	7389·81	113	10028·75
91	6503·88	¼	7427·95	114	10207·03
¼	6539·67	½	7466·19	115	10386·88
½	6575·55	¾	7504·53	116	10568·31
¾	6611·53	98	7542·96	117	10751·31
92	6647·61	¼	7581·5	118	10935·88
¼	6683·79	½	7620·13	119	11122·02
½	6720·06	¾	7658·86	120	11309·72
¾	6756·44	99	7697·69		

TABLE OF SQUARES AND CUBES.

No.	Square.	Cube.	No.	Square.	Cube.
1	1	1	44	1936	85184
2	4	8	45	2025	91125
3	9	27	46	2116	97336
4	16	64	47	2209	103823
5	25	125	48	2304	110592
6	36	216	49	2401	117649
7	49	343	50	2500	125000
8	64	512	51	2601	132651
9	81	729	52	2704	140608
10	100	1300	53	2809	148877
11	121	1331	54	2916	157464
12	144	1728	55	3025	166375
13	169	2197	56	3136	175616
14	196	2744	57	3249	185193
15	225	3375	58	3364	195112
16	256	4096	59	3481	205379
17	289	4913	60	3600	216000
18	324	5832	61	3721	226981
19	361	6859	62	3844	238328
20	400	8000	63	3969	250047
21	441	9261	64	4096	262144
22	484	10648	65	4225	274625
23	529	12167	66	4356	287496
24	576	13824	67	4489	300763
25	625	15625	68	4624	314432
26	676	17576	69	4761	328509
27	729	19683	70	4900	343000
28	784	21952	71	5041	357911
29	841	24389	72	5184	373248
30	900	27000	73	5329	389017
31	961	29791	74	5476	405224
32	1024	32768	75	5625	421875
33	1089	35937	76	5776	438976
34	1156	39304	77	5929	456533
35	1225	42875	78	6084	474552
36	1296	46656	79	6241	493039
37	1369	50653	80	6400	512000
38	1444	54872	81	6561	531441
39	1521	59319	82	6724	551368
40	1600	64000	83	6889	571787
41	1681	68921	84	7056	592704
42	1764	74088	85	7225	614125
43	1849	79507	86	7396	636056

No.	Square.	Cube.	No.	Square.	Cube.
87	7569	658503	134	17956	2406104
88	7744	681472	135	18225	2460375
89	7921	704969	136	18496	2515456
90	8100	729000	137	18769	2571353
91	8281	753571	138	19044	2620872
92	8464	778688	139	19321	2685619
93	8649	804357	140	19600	2744000
94	8836	830584	141	19881	2803221
95	9025	857375	142	20164	2863288
96	9216	884736	143	20449	2924207
97	9409	912673	144	20736	2985984
98	9604	941192	145	21025	3048625
99	9801	970299	146	21316	3112136
100	10000	1000000	147	21609	3176523
101	10201	1030301	148	21904	3241792
102	10404	1061208	149	22201	3307949
103	10609	1092727	150	22500	3375000
104	10816	1124864	151	22801	3442951
105	11025	1157625	152	23104	3511808
106	11236	1191016	153	23409	3581577
107	11449	1225043	154	23716	3652264
108	11664	1259712	155	24025	3723875
109	11881	1295028	156	24336	3796416
110	12100	1331000	157	24649	3869893
111	12321	1367631	158	24964	3944312
112	12544	1404920	159	25281	4019679
113	12769	1442897	160	25600	4096000
114	12996	1481544	161	25921	4173281
115	13225	1520875	162	26244	4251528
116	13456	1560896	163	26569	4330747
117	13689	1601613	164	26896	4410944
118	13924	1643032	165	27225	4492125
119	14161	1685159	166	27556	4574296
120	14400	1728000	167	27889	4657453
121	14641	1771561	168	28224	4741632
122	14884	1815848	169	28561	4826809
123	15129	1860867	170	28900	4913000
124	15376	1906624	171	29241	5000211
125	15625	1953125	172	29584	5088448
126	15876	2000376	173	29929	5177717
127	16129	2048383	174	30276	5268024
128	16384	2097152	175	30625	5359375
129	16641	2146689	176	30976	5451776
130	16900	2197000	177	31329	5545233
131	17161	2248091	178	31684	5639752
132	17424	2299968	179	32041	5735339
133	17689	2352637	180	32400	5832000

No.	Square.	Cube.	No.	Square.	Cube.
181	32761	5929741	228	51984	11852352
182	33124	6028568	229	52441	12008989
183	33489	6128487	230	52900	12167000
184	33856	6229504	231	53361	12326391
185	34225	6331625	232	53824	12487168
186	34596	6434856	233	54289	12649337
187	34969	6539203	234	54756	12812904
188	35344	6644672	235	55225	12977875
189	35721	6751269	236	55696	13144256
190	36100	6859000	237	56169	13312053
191	36481	6967871	238	56644	13481272
192	36864	7077888	239	57121	13651919
193	37249	7189057	240	57600	13824000
194	37636	7301384	241	58081	13997521
195	38025	7414875	242	58564	14172488
196	38416	7529536	243	59049	14348907
197	38809	7645373	244	59536	14526784
198	39204	7762392	245	60025	14706125
199	39601	7880599	246	60516	14886936
200	40000	8000000	247	61009	15069223
201	40401	8120601	248	61504	15252992
202	40804	8242408	249	62001	15438249
203	41209	8365427	250	62500	15625000
204	41616	8489664	251	63001	15813251
205	42025	8615125	252	63504	16003008
206	42436	8741816	253	64009	16194277
207	42849	8869743	254	64516	16387064
208	43264	8998912	255	65025	16581375
209	43681	9123329	256	65536	16777216
210	44100	9261000	257	66049	16974593
211	44521	9393931	258	66564	17173512
212	44944	9528128	259	67081	17373979
213	45369	9663597	260	67600	17576000
214	45796	9800344	261	68121	17779581
215	46225	9938375	262	68644	17984728
216	46656	10077696	263	69169	18191447
217	47089	10218313	264	69696	18399744
218	47524	10360232	265	70225	18609625
219	47961	10503459	266	70756	18821096
220	48400	10648000	267	71289	19034163
221	48841	10793861	268	71824	19248832
222	49284	10941048	269	72361	19465109
223	49729	11089567	270	72900	19683000
224	50176	11239424	271	73441	19902511
225	50625	11390625	272	73984	20123648
226	51076	11543176	273	74529	20346417
227	51529	11697083	274	75076	20570824

No.	Square.	Cube.	No.	Square.	Cube.
275	75625	20796875	322	103684	33386248
276	76176	21024576	323	104329	33698267
277	76729	21253933	324	104976	34012224
278	77284	21484952	325	105625	34328125
279	77841	21717639	326	106276	34645976
280	78400	21952000	327	106929	34965783
281	78961	22188041	328	107584	35287552
282	79524	22425768	329	108241	35611289
283	80089	22665187	330	108900	35937000
284	80656	22906304	331	109561	36264691
285	81225	23149125	332	110224	36594368
286	81796	23393656	333	110889	36926037
287	82369	23639903	334	111556	37259704
288	82944	23887872	335	112225	37595375
289	83521	24137569	336	112896	37933056
290	84100	24389000	337	113569	38272753
291	84681	24642171	338	114244	38614472
292	85264	24897088	339	114921	38958219
293	85849	25153757	340	115600	39304000
294	86436	25412184	341	116281	39651821
295	87025	25672375	342	116964	40001688
296	87616	25934336	343	117649	40353607
297	88209	26198073	344	118336	40707584
298	88804	26463592	345	119025	41063625
299	89401	26730899	346	119716	41421736
300	90000	27000000	347	120409	41781923
301	90601	27270901	348	121104	42144192
302	91204	27543608	349	121801	42508549
303	91809	27818127	350	122500	42875000
304	92416	28094464	351	123201	43243551
305	93025	28372625	352	123904	43614208
306	93636	28652616	353	124609	43986977
307	94249	28934443	354	125316	44361864
308	94864	29218112	355	126025	44738875
309	95481	29503629	356	126736	45118016
310	96100	29791000	357	127449	45499293
311	96721	30080231	358	128164	45882712
312	97344	30371328	359	128881	46268279
313	97969	30664297	360	129600	46656000
314	98596	30959144	361	130321	47045881
315	99225	31255875	362	131044	47437928
316	99856	31554496	363	131769	47832147
317	100489	31855013	364	132496	48228544
318	101124	32157432	365	133225	48627125
319	101761	32461759	366	133956	49027896
320	102400	32768000	367	134689	49430863
321	103041	33076161	368	135424	49836032

No.	Square.	Cube.	No.	Square.	Cube.
369	136161	50243409	416	173056	71991296
370	136900	50653000	417	173889	72511713
371	137641	51064811	418	174724	73034632
372	138384	51478848	419	175561	73560059
373	139129	51895117	420	176400	74088000
374	139876	52313624	421	177241	74618461
375	140625	52734375	422	178084	75151448
376	141376	53157376	423	178929	75686967
377	142129	53582633	424	179776	76225024
378	142884	54010152	425	180625	76765625
379	143641	54439939	426	181476	77308776
380	144400	54872000	427	182329	77854483
381	145161	55306341	428	183184	78402752
382	145924	55742968	429	184041	78953589
383	146689	56181887	430	184900	79507000
384	147456	56623104	431	185761	80062991
385	148225	57066625	432	186624	80621568
386	148996	57512456	433	187489	81182737
387	149769	57960603	434	188356	81746504
388	150544	58411072	435	189225	82312875
389	151321	58863869	436	190096	82881856
390	152100	59319000	437	190969	83453453
391	152881	59776471	438	191844	84027672
392	153664	60236288	439	192721	84604519
393	154449	60698457	440	193600	85184000
394	155236	61162984	441	194481	85766121
395	156025	61629875	442	195364	86350388
396	156816	62099136	443	196249	86938307
397	157609	62570773	444	197136	87528384
398	158404	63044792	445	198025	88121125
399	159201	63521199	446	198916	88716536
400	160000	64000000	447	199809	89314623
401	160801	64481201	448	200704	89915392
402	161604	64964808	449	201601	90518849
403	162409	65450827	450	202500	91125000
404	163216	65939264	451	203401	91733851
405	164025	66430125	452	204304	92345408
406	164836	66923416	453	205209	92959677
407	165649	67419143	454	206106	93576664
408	166464	67911312	455	207025	94196375
409	167281	68417929	456	207936	94818816
410	168100	68921000	457	208849	95443993
411	168921	69426531	458	209764	96071912
412	169744	69934528	459	210681	96702579
413	170569	70444997	460	211600	97336000
414	171396	70957944	461	212521	97972181
415	172225	71473375	462	213444	98611128

No.	Square.	Cube.	No.	Square.	Cube.
463	214369	99252847	510	260100	132651000
464	215296	99897344	511	261121	133432831
465	216225	100544625	512	262144	134217728
466	217156	101194696	513	263169	135005697
467	218089	101847563	514	264196	135796744
468	219024	102503232	515	265225	136590875
469	219961	103161709	516	266256	137388096
470	220900	103823000	517	267289	138188413
471	221841	104487111	518	268324	138991832
472	222784	105154048	519	269361	139798359
473	223729	105823817	520	270400	140608000
474	224676	106496424	521	271441	141420761
475	225625	107171875	522	272484	142236648
476	226576	107850176	523	273529	143055667
477	227529	108531333	524	274576	143877824
478	228484	109215352	525	275625	144703125
479	229441	109902239	526	276676	145531576
480	230400	110592000	527	277729	146363183
481	231361	111284641	528	278784	147197952
482	232324	111980168	529	279841	148035889
483	233289	112678587	530	280900	148877000
484	234256	113379904	531	281961	149721291
485	235225	114084125	532	283024	150568768
486	236196	114791256	533	284089	151419437
487	237169	115501303	534	285156	152273304
488	238144	116214272	535	286225	153130375
489	239121	116930169	536	287296	153990656
490	240100	117649000	537	288369	154854153
491	241081	118370771	538	289444	155720872
492	242064	119095488	539	290521	156590819
493	243049	119823157	540	291600	157464000
494	244036	120553784	541	292681	158340421
495	245025	121287375	542	293764	159220088
496	246016	122023936	543	294849	160103007
497	247009	122763473	544	295936	160989184
498	248004	123505992	545	297025	161878625
499	249001	124251499	546	298116	162771336
500	250000	125000000	547	299209	163667323
501	251001	125751501	548	300304	164566592
502	252004	126506008	549	301401	165469149
503	253009	127263527	550	302500	166375000
504	254016	128024864	551	303601	167284151
505	255025	128787625	552	304704	168196608
506	256036	129554216	553	305809	169112377
507	257049	130323843	554	306916	170031464
508	258064	131096512	555	308025	170953875
509	259081	131872229	556	309136	171879616

No.	Square.	Cube.	No.	Square.	Cube.
557	310249	172808693	604	364816	220348864
558	311364	173741112	605	366025	221445125
559	312481	174676879	606	367236	222545016
560	313600	175616000	607	368449	223648543
561	314721	176558481	608	369664	224755712
562	315844	177504328	609	370881	225866529
563	316969	178453547	610	372100	226981000
564	318096	179406144	611	373321	228099131
565	319225	180362125	612	374544	229220928
566	320356	181321496	613	375769	230346397
567	321489	182284263	614	376996	231475544
568	322624	183250432	615	378225	232608375
569	323761	184220009	616	379456	233744896
570	324900	185193000	617	380689	234885113
571	326041	186169411	618	381924	236029032
572	327184	187149248	619	383161	237176659
573	328329	188132517	620	384400	238328000
574	329476	189119224	621	385641	239483061
575	330625	190109375	622	386884	240641848
576	331776	191102976	623	388129	241804367
577	332929	192100033	624	389376	242970624
578	334084	193100552	625	390625	244140625
579	335241	194104539	626	391876	245314376
580	336400	195112000	627	393129	246491883
581	337561	196122941	628	394384	247673152
582	338724	197137368	629	395641	248858189
583	339889	198155287	630	396900	250047000
584	341056	199176704	631	398161	251239591
585	342225	200201625	632	399424	252435968
586	343396	201230056	633	400689	253636137
587	344569	202262003	634	401956	254840104
588	345744	203297472	635	403225	256047875
589	346921	204336469	636	404496	257259456
590	348100	205379000	637	405769	258474853
591	349281	206425071	638	407044	259694072
592	350464	207474688	639	408321	260917119
593	351649	208527857	640	409600	262144000
594	352836	209584584	641	410881	263374721
595	354025	210644875	642	412164	264609288
596	355216	211708736	643	413449	265847707
597	356409	212776173	644	414736	267089984
598	357604	213847192	645	416025	268336125
599	358801	214921799	646	417316	269586136
600	360000	216000000	647	418609	270840023
601	361201	217081801	648	419904	272097792
602	362404	218167208	649	421201	273359449
603	363609	219256227	650	422500	274625000

No.	Square.	Cube.	No.	Square.	Cube.
651	423801	275894451	698	487204	340068392
652	425104	277167808	699	488601	341532099
653	426409	278445077	700	490000	343000000
654	427716	279726264	701	491401	344472101
655	429025	281011375	702	492804	345948088
656	430336	282300416	703	494209	347428927
657	431649	283593393	704	495616	348913664
658	432964	284890312	705	497025	350402625
659	434281	286191179	706	498436	351895816
660	435600	287496000	707	499849	353393243
661	436921	288804781	708	501264	354894912
662	438244	290117528	709	502681	356400829
663	439569	291434247	710	504100	357911000
664	440896	292754944	711	505521	359425431
665	442225	294079625	712	506944	360944128
666	443556	295408296	713	508369	362467097
667	444889	296740963	714	509796	363994344
668	446224	298077632	715	511225	365525875
669	447561	299418309	716	512656	367061696
670	448900	300763000	717	514089	368601813
671	450241	302111711	718	515524	370146232
672	451584	303464448	719	516961	371694959
673	452929	304821217	720	518400	373248000
674	454276	306182024	721	519841	374805361
675	455625	307546875	722	521284	376367048
676	456976	308915776	723	522729	377933067
677	458329	310288733	724	524176	379503424
678	459684	311665752	725	525625	381078125
679	461041	313046839	726	527076	382657176
680	462400	314432000	727	528529	384240583
681	463761	315821241	728	529984	385828352
682	465124	317214568	729	531441	387420489
683	466489	318611987	730	532900	389017000
684	467856	320013504	731	534361	390617891
685	469225	321419125	732	535824	392223168
686	470596	322828856	733	537289	393832837
687	471969	324242703	734	538756	395446904
688	473344	325660672	735	540225	397065375
689	474721	327082769	736	541696	398688256
690	476100	328509000	737	543169	400315553
691	477481	329939371	738	544644	401947272
692	478864	331373888	739	546121	403583419
693	480249	332812557	740	547600	405224000
694	481636	334255384	741	549081	406869021
695	483025	335702375	742	550564	408518488
696	484416	337153536	743	552049	410172407
697	485809	338608873	744	553536	411830784

No.	Square.	Cube.	No.	Square.	Cube.
745	555025	413493625	792	627264	496793088
746	556516	415160936	793	628849	498677257
747	558009	416832723	794	630436	500566184
748	559504	418508992	795	632025	502459875
749	561001	420189749	796	633616	504358336
750	562500	421875000	797	635209	506261573
751	564001	423564751	798	636804	508169592
752	565504	425259008	799	638401	510082399
753	567009	426957777	800	640000	512000000
754	568516	428661064	801	641601	513922401
755	570025	430368875	802	643204	515849608
756	571536	432081216	803	644809	517781627
757	573049	433798093	804	646416	519718464
758	574564	435519512	805	648025	521660125
759	576081	437245479	806	649636	523606616
760	577600	438976000	807	651249	525557943
761	579121	440711081	808	652864	527514112
762	580644	442450728	809	654481	529475129
763	582169	444194947	810	656100	531441000
764	583696	445943744	811	657721	533411731
765	585225	447697125	812	659344	535387328
766	586756	449455096	813	660969	537366797
767	588289	451217663	814	662596	539353144
768	589824	452984832	815	664225	541343375
769	591361	454756609	816	665856	543338496
770	592900	456533000	817	667489	545338513
771	594441	458314011	818	669124	547343432
772	595984	460099648	819	670761	549353259
773	597529	461889917	820	672400	551368000
774	599076	463684824	821	674041	553387661
775	600625	465484375	822	675684	555412248
776	602176	467288576	823	677329	557441767
777	603729	469097433	824	678976	559476224
778	605284	470910952	825	680625	561515625
779	606841	472729139	826	682276	563559976
780	608400	474552000	827	683929	565609283
781	609961	476379541	828	685584	567663552
782	611524	478211768	829	687241	569722789
783	613089	480048687	830	688900	571787000
784	614656	481890304	831	690561	573856191
785	616225	483736025	832	692224	575930368
786	617796	485587656	833	693889	578009537
787	619369	487443403	834	695556	580093704
788	620944	489303872	835	697225	582182875
789	622521	491169069	836	698896	584277056
790	624100	493039000	837	700569	586376253
791	625681	494913671	838	702244	588480472

No.	Square.	Cube.	No.	Square.	Cube.
839	703921	590589719	886	784996	695506456
840	705600	592704000	887	786769	697864103
841	707281	594823321	888	788544	700227072
842	708964	596947688	889	790321	702595369
843	710649	599077107	890	792100	704969000
844	712336	601211584	891	793881	707347971
845	714025	603351125	892	795664	709732288
846	715716	605495736	893	797449	712121957
847	717409	607645423	894	799236	714516984
848	719104	609800192	895	801025	716917375
849	720801	611960049	896	802816	719323136
850	722500	614125000	897	804609	721734273
851	724201	616295051	898	806404	724150792
852	725904	618470208	899	808201	726572699
853	727609	620650477	900	810000	729000000
854	729316	622835864	901	811804	731432701
855	731025	625026375	902	813604	733870808
856	732736	627222016	903	815409	736314327
857	734449	629422793	904	817216	738763264
858	736164	631628712	905	819025	741217625
859	737881	633839779	906	820836	743677416
860	739600	636056000	907	822649	746142643
861	741321	638277381	908	824464	748613312
862	743044	640503928	909	826281	751089429
863	744769	642735647	910	828100	753571000
864	746496	644972544	911	829921	756058031
864	748225	647214625	912	831744	758550528
866	749956	649461896	913	833569	761048497
867	751689	651714363	914	835396	763551944
868	753424	653972032	915	837225	766060875
869	755161	656234909	916	839056	768575296
870	756900	658503000	917	840889	771095213
871	758641	660776311	918	842724	773620632
872	760384	663054848	919	844561	776151559
873	762129	665338617	920	846400	778688000
874	763876	667627624	921	848241	781229961
875	765625	669921875	922	850084	783777448
876	767376	672221376	923	851929	786330467
877	769129	674526133	924	853776	788889024
878	770884	676836152	925	855625	791453125
879	772641	679151439	926	857476	794022776
880	774400	681472000	927	859329	796597983
881	776161	683797841	928	861184	799178752
882	777924	686128968	929	863041	801765089
883	779689	688465387	930	864900	804357000
884	781456	690807104	931	866761	806954491
885	783225	693154125	932	868624	809557568

No.	Square.	Cube.	No.	Square.	Cube.
933	870489	812166237	967	935089	904231063
934	872356	814780504	968	937024	907039232
935	874225	817400375	969	938961	909853209
936	876096	820025856	970	940900	912673000
937	877969	822656953	971	942841	915498611
938	879844	825293672	972	944784	918330048
939	881721	827936019	973	946729	921167317
940	883600	830584000	974	948676	924010424
941	885481	833237621	975	950625	926859375
942	887364	835896888	976	952576	929714176
943	889249	838561807	977	654529	932574833
944	891136	841232384	978	956484	935441352
945	893025	843908625	979	958441	938313739
946	894916	846590536	980	960400	941192000
947	896809	849278123	981	962361	944076141
948	898704	851971392	982	964324	946966168
949	900601	854670349	983	966289	949682087
950	902500	857375000	984	968256	952763904
951	904401	860085351	985	970225	955671625
952	906304	862801408	986	972196	958585256
953	908209	865523177	987	974169	961504803
954	910116	868250664	988	976144	964430272
955	912025	870983875	989	978121	967361669
956	913936	873722816	990	980100	970299000
957	915849	876467493	991	982081	973242271
958	917764	873217912	992	984064	976191488
959	919681	881974079	993	986049	979146657
960	921600	884736000	994	988036	982107784
961	923521	887503681	995	990025	985074875
962	925444	890277128	996	992016	988047936
963	927369	893056347	997	994009	991026973
964	929296	895841344	998	996004	994011992
965	931225	898632125	999	998001	997002999
966	933156	901428696			

TABLE OF SQUARE AND CUBE ROOTS.

No.	Square Root.	Cube Root.	No.	Square Root.	Cube Root.
1	1	1	41	6·403	3·448
2	1·414	1·26	42	6·481	3·476
3	1·732	1·442	43	6·557	3·503
4	2	1·587	44	6·633	3·53
5	2·236	1·71	45	6·708	3·557
6	2·449	1·817	46	6·782	3·583
7	2·646	1·913	47	6·856	3·609
8	2·828	2	48	6·928	3·634
9	3	2·08	49	7	3·659
10	3·162	2·154	50	7·071	3·684
11	3·317	2·124	51	7·141	3·708
12	3·464	2·289	52	7·211	3·733
13	3·606	2·351	53	7·28	3·756
14	3·742	2·41	54	7·348	3·78
15	3·873	2·466	55	7·416	3·803
16	4	2·52	56	7·483	3·826
17	4·123	2·571	57	7·55	3·849
18	4·243	2·621	58	7·616	3·871
19	4·359	2·668	59	7·681	3·893
20	4·472	2·714	60	7·746	3·915
21	4·583	2·759	61	7·81	3·936
22	4·69	2·802	62	7·874	3·958
23	4·796	2·844	63	7·937	3·979
24	4·899	2·884	64	8	4
25	5	2·924	65	8·062	4·021
26	5·099	2·962	66	8·124	4·041
27	5·196	3	67	8·185	4·062
28	5·292	3·037	68	8·246	4·082
29	5·385	3·072	69	8·307	4·102
30	5·477	3·107	70	8·367	4·121
31	5·568	3·141	71	8·426	4·141
32	5·657	3·175	72	8·485	4·16
33	5·745	3·208	73	8·544	4·179
34	5·831	3·24	74	8·602	4·198
35	5·916	3·271	75	8·66	4·217
36	6	3·302	76	8·718	4·236
37	6·083	3·332	77	8·775	4·254
38	6·164	3·362	78	8·832	4·273
39	6·245	3·391	79	8·888	4·291
40	6·325	3·42	80	8·914	4·309

No.	Square Root.	Cube Root.	No.	Square root.	Cube Root.
81	9	4·327	128	11·314	5·04
82	9·055	4·344	129	11·358	5·053
83	9·11	4·362	130	11·402	5·066
84	9·165	4·38	131	11·446	5·079
85	9·22	4·397	132	11·489	5·092
86	9·274	4·414	133	11·533	5·104
87	9·327	4·431	134	11·576	5·117
88	9·381	4·448	135	11·619	5·13
89	9·434	4·465	136	11·662	5·143
90	9·487	4·481	137	11·705	5·155
91	9·539	4·498	138	11·747	5·168
92	9·592	4·514	139	11·79	5·18
93	9·644	4·531	140	11·832	5·192
94	9·695	4·547	141	11·874	5·205
95	9·747	4·563	142	11·916	5·217
96	9·798	4·579	143	11·958	5·229
97	9·849	4·595	144	12	5·241
98	9·899	4·61	145	12·042	5·254
99	9·95	4·626	146	12·083	5·266
100	10	4·642	147	12·124	5·278
101	10·05	4·657	148	12·166	5·29
102	10·1	4·672	149	12·207	5·301
103	10·149	4·688	150	12·247	5·313
104	10·198	4·703	151	12·288	5·325
105	10·247	4·718	152	12·329	5·337
106	10·296	4·733	153	12·369	5·348
107	10·344	4·747	154	12·41	5·36
108	10·392	4·762	155	12·45	5·372
109	10·44	4·777	156	12·49	5·383
110	10·488	4·791	157	12·53	5·395
111	10·536	4·806	158	12·57	5·406
112	10·583	4·82	159	12·61	5·418
113	10·63	4·835	160	12·649	5·429
114	10·677	4·849	161	12·689	5·44
115	10·724	4·863	162	12·728	5·451
116	10·77	4·877	163	12·767	5·463
117	10·817	4·891	164	12·806	5·474
118	10·863	4·905	165	12·845	5·485
119	10·909	4·919	166	12·884	5·496
120	10·954	4·932	167	12·923	5·507
121	11	4·946	168	12·961	5·518
122	11·045	4·96	169	13	5·529
123	11·091	4·973	170	13·038	5·54
124	11·136	4·987	171	13·077	5·55
125	11·18	5	172	13·115	5·561
126	11·225	5·013	173	13·153	5·572
127	11·269	5·027	174	13·191	5·583

No.	Square Root.	Cube Root.	No.	Square Root.	Cube Root.
175	13·229	5·593	222	14·9	6·055
176	13·266	5·604	223	14·933	6·064
177	13·304	5·615	224	14·967	6·073
178	13·342	5·625	225	15	6·082
179	13·379	5·636	226	15·033	6·091
180	13·416	5·646	227	15·067	6·1
181	13·454	5·657	228	15·1	6·109
182	13·491	5·667	229	15·133	6·118
183	13·528	5·677	230	15·166	6·127
184	13·565	5·688	231	15·199	6·136
185	13·601	5·698	232	15·232	6·145
186	13·638	5·708	233	15·264	6·153
187	13·675	5·718	234	15·297	6·162
188	13·711	5·729	235	15·33	6·171
189	13·748	5·739	236	15·362	6·18
190	13·784	5·749	237	15·395	6·188
191	13·82	5·759	238	15·427	6·197
192	13·856	5·769	239	15·46	6·206
193	13·892	5·779	240	15·492	6·214
194	13·928	5·789	241	15·524	6·223
195	13·964	5·799	242	15·556	6·232
196	14	5·809	243	15·588	6·24
197	14·036	5·819	244	15·62	6·249
198	14·071	5·828	245	15·652	6·257
199	14·107	5·838	246	15·684	6·266
200	14·142	5·848	247	15·716	6·274
201	14·177	5·858	248	15·748	6·283
202	14·213	5·867	249	15·78	6·291
203	14·248	5·877	250	15·811	6·3
204	14·283	5·887	251	15·843	6·308
205	14·318	5·896	252	15·875	6·316
206	14·353	5·906	253	15·906	6·325
207	14·387	5·915	254	15·937	6·333
208	14·422	5·925	255	15·969	6·341
209	14·457	5·934	256	16	6·35
210	14·491	5·944	257	16·031	6·358
211	14·526	5·953	258	16·062	6·366
212	14·56	5·963	259	16·093	6·374
213	14·595	5·972	260	16·125	6·383
214	14·629	5·981	261	16·155	6·391
215	14·663	5·991	262	16·186	6·399
216	14·697	6	263	16·217	6·407
217	14·731	6·009	264	16·248	6·415
218	14·765	6·018	265	16·279	6·423
219	14·799	6·028	266	16·31	6·431
220	14·832	6·037	267	16·34	6·439
221	14·866	6·046	268	16·371	6·447

No.	Square Root.	Cube Root.	No.	Square Root.	Cube Root.
269	16·401	6·455	316	17·776	6·811
270	16·432	6·463	317	17·804	6·818
271	16·462	6·471	318	17·833	6·826
272	16·492	6·479	319	17·861	6·833
273	16·523	6·487	320	17·889	6·84
274	16·553	6·495	321	17·916	6·847
275	16·583	6·503	322	17·944	6·854
276	16·613	6·511	323	17·972	6·861
277	16·643	6·519	324	18	6·868
278	16·673	6·527	325	18·028	6·875
279	16·703	6·534	326	18·055	6·882
280	16·733	6·542	327	18·083	6·889
281	16·763	6·55	328	18·111	6·896
282	16·793	6·558	329	18·138	6·903
283	16·823	6·565	330	18·166	6·91
284	16·852	6·573	331	18·193	6 917
285	16·882	6·581	332	18·221	6·924
286	16·912	6·589	333	18·248	6·931
287	16·941	6·596	334	18·276	6·938
288	16·971	6·604	335	18·303	6·945
289	17	6 611	336	18 33	6·952
290	17·029	6·619	337	18·358	6·959
291	17·059	6·627	338	18·385	6·966
292	17·088	6·634	339	18·412	6·973
293	17·117	6·642	340	18 439	6·98
294	17·146	6·649	341	18·466	6·986
295	17·176	6·657	342	18·493	6·993
296	17·205	6·664	343	18·52	7
297	17·234	6·672	344	18·547	7·007
298	17·263	6·679	345	18·574	7·014
299	17·292	6·687	346	18·601	7·02
300	17·321	6·694	347	18·628	7·027
301	17·349	6·702	348	18·655	7·034
302	17·378	6·709	349	18·682	7·041
303	17·407	6·717	350	18·708	7·047
304	17·436	6·724	351	18·735	7·054
305	17·464	6·731	352	18·762	7·061
306	17·493	6·739	353	18·788	7·067
307	17·521	6·746	354	18·815	7 074
308	17·550	6·753	355	18·841	7·081
309	17·578	6·761	356	18·868	7·087
310	17·607	6·768	357	18·894	7·094
311	17·635	6·775	358	18·921	7·101
312	17·664	6·782	359	18·947	7·107
313	17·692	6·79	360	18·974	7·114
314	17·72	6·797	361	19	7·12
315	17·748	6·804	362	19·026	7·127

No.	Square Root.	Cube Root.	No.	Square Root.	Cube Root.
363	19·053	7·133	410	20·248	7·429
364	19·079	7·14	411	20·273	7·435
365	19·105	7·147	412	20·298	7·441
366	19·131	7·153	413	20·322	7·447
367	19·157	7·16	414	20·347	7·453
368	19·183	7·166	415	20·372	7·459
369	19·209	7·173	416	20·396	7·465
370	19·235	7·179	417	20·421	7·471
371	19·261	7·186	418	20·445	7·477
372	19·287	7·192	419	20·469	7·483
373	19·313	7·198	420	20·494	7·489
374	19·339	7·205	421	20·518	7·495
375	19·365	7·211	422	20·543	7·501
376	19·391	7·218	423	20·567	7·507
377	19·416	7·224	424	20·591	7·513
378	19·442	7·23	425	20·616	7·518
379	19 468	7·237	426	20·64	7·524
380	19·494	7·243	427	20·664	7·53
381	19·519	7·25	428	20·688	7·536
382	19·545	7·256	429	20·712	7·542
383	19·57	7·262	430	20·736	7·548
384	19·596	7·268	431	20·761	7·554
385	19·621	7·275	432	20·785	7·56
386	19·647	7·281	433	20·809	7·565
387	19·672	7·287	434	20·833	7·571
388	19·698	7·294	435	20·857	7·577
389	19·723	7·3	436	20·881	7·583
390	19·748	7·306	437	20·905	7·589
391	19·774	7·312	438	20·928	7·594
392	19·799	7·319	439	20·952	7·6
393	19·824	7·325	440	20 976	7·606
394	19·849	7·331	441	21	7·612
395	19·875	7·337	442	21·024	7·617
396	19·9	7·343	443	21·048	7·623
397	19·925	7·35	444	21·071	7·629
398	19·95	7·356	445	21·095	7·635
399	19·975	7·362	446	21·119	7·64
400	20	7·368	447	21·142	7·646
401	20·025	7·374	448	21·166	7·652
402	20·05	7·38	449	21·19	7·657
403	20·075	7·386	450	21·213	7·663
404	20·1	7·393	451	21·237	7·669
405	20·125	7·399	452	21·26	7·674
406	20·149	7·405	453	21·284	7·68
407	20·174	7·411	454	21·307	7·686
408	20·199	7·417	455	21·331	7·691
409	20·224	7·423	456	21·354	7·697

No.	Square Root.	Cube Root.	No.	Square Root.	Cube Root.
457	21·378	7·703	504	22·450	7·958
458	21·401	7·708	505	22·472	7·963
459	21·424	7·714	506	22·494	7·969
460	21·448	7·719	507	22·517	7·974
461	21·471	7·725	508	22·539	7·979
462	21·494	7·731	509	22·561	7·984
463	21·517	7·736	510	22·583	7·99
464	21·541	7·742	511	22·605	7·995
465	21·564	7·747	512	22·627	8
466	21·587	7·753	513	22·65	8·005
467	21·61	7·758	514	22·672	8·01
468	21·638	7·764	515	22·694	8·016
469	21·656	7·769	516	22·716	8·021
470	21·679	7·775	517	22·738	8·026
471	21·703	7·78	518	22·76	8·031
472	21·726	7·786	519	22·782	8·036
473	21·749	7·791	520	22·804	8·041
474	21·772	7·797	521	22·825	8·047
475	21·794	7·802	522	22·847	8·052
476	21·817	7·808	523	22·869	8·057
477	21·840	7·813	524	22·891	8·062
478	21·863	7·819	525	22·913	8·067
479	21·886	7·824	526	22·935	8·072
480	21·909	7·83	527	22·956	8·077
481	21·932	7·835	528	22·978	8·082
482	21·954	7·841	529	23	8·088
483	21·977	7·846	530	23·022	8·093
484	22	7·851	531	23·043	8·098
485	22·023	7·857	532	23·065	8·103
486	22·045	7.862	533	23·087	8·108
487	22·069	7·868	534	23·108	8·113
488	22·091	7·873	535	23·13	8·118
489	22·113	7·878	536	23·152	8·123
490	22·136	7·884	537	23·173	8·128
491	22·159	7·889	538	23·195	8·133
492	22·181	7·894	539	23·216	8·138
493	22·204	7·9	540	23·238	8·143
494	22·226	7·905	541	23·259	8·148
495	22·249	7·910	542	23·281	8·153
496	22·271	7·916	543	23·302	8·158
497	22·293	7.921	544	23·324	8·163
498	22·216	7·926	545	23·345	8·168
499	22·339	7·932	546	23·367	8·173
500	22·361	7·937	547	23·388	8·178
501	22·383	7·942	548	23·409	8·183
502	22·405	7·948	549	23·431	8·188
503	22·428	7·953	550	23·452	8·193

No.	Square Root.	Cube Root.	No.	Square Root.	Cube Root.
551	23·473	8·198	598	24·454	8·425
552	23·495	8·203	599	24·474	8·43
553	23·516	8·208	600	24·495	8·434
554	53·537	8·213	601	24·515	8·439
555	23·558	8·218	602	24·536	8·444
556	23·58	8·223	603	24·556	8·448
557	23·601	8·228	604	24·576	8·453
558	23·622	8·233	605	24·597	8·458
559	23·643	8·238	606	24·617	8·462
560	23·664	8·243	607	24·637	8·467
561	23·685	8·247	608	24·658	8·472
562	23·707	8·252	609	24·678	8·476
563	23·728	8·257	610	24·698	8·481
564	23·749	8·262	611	24·718	8·486
565	23·770	8·267	612	24·739	8·49
566	23·791	8·272	613	24·759	8·495
567	23·812	8·277	614	24·779	8.499
568	23·833	8·282	615	24·799	8·504
569	23·854	8·286	616	24·819	8·509
570	23·875	8·291	617	24·839	8·513
571	23·896	8·296	618	24·86	8·518
572	23·917	8·301	619	24·88	8·522
573	23·937	8·306	620	24·9	8·527
574	23·958	8·311	621	24·92	8·532
575	23·979	8·316	622	24·94	8·536
576	24	8·32	623	24·96	8·541
577	24·021	8·325	624	24·98	8·545
578	24·042	8·33	625	25	8·55
579	24·062	8·335	626	25·02	8·554
580	24·083	8·34	627	25·04	8·559
581	24·104	8·344	628	25·06	8·564
582	24·125	8·349	629	25·08	8·568
583	24·145	8·354	630	25·1	8·573
584	24·166	8·359	631	25·12	8·577
585	24·187	8·363	632	25·14	8·582
586	24·207	8·368	633	25·159	8·586
587	24·228	8·373	634	25·179	8·591
588	24·249	8·378	635	25·199	8·595
589	24·269	8·382	636	25·219	8·6
590	24·29	8·387	637	25·239	8·604
591	24·31	8·392	938	25·259	8·609
592	24·331	8·397	639	25·278	8·613
593	24·352	8·401	640	25·298	8·618
594	24·372	8·406	641	25·318	8·622
595	24·393	8·411	642	25·338	8·627
596	24·413	8·416	643	25·357	8·631
597	24·434	8·42	644	25·377	8·636

No.	Square Root.	Cube Root.	No.	Square Root.	Cube Root.
645	25·397	8·64	692	26·306	8 845
646	25·417	8·645	693	26·325	8·849
647	25·436	8·649	694	26·344	8·854
648	25·456	8·653	695	26·363	8·858
649	25·475	8·658	696	26·382	8·862
650	25·495	8·662	697	26·401	8·866
651	25·515	8·667	698	26·42	8·871
652	25·534	8·671	699	26 439	8·875
653	25·554	8·676	700	26·458	8·879
654	25·573	8·68	701	26·476	8·883
655	25·593	8·685	702	26·495	8·887
656	25·612	8·689	703	26·514	8·892
657	25·632	8·693	704	26·533	8·896
658	25·652	8·698	705	26·552	8·9
659	25·671	8·702	706	26·571	8·904
660	25·69	8·707	707	26·589	8·909
661	25·71	8·711	708	26·608	8·913
662	25·72	8·715	709	26·627	8·917
663	25·749	8·72	710	26·646	8·921
664	25·768	8·724	711	26·665	8·925
665	25·788	8·729	712	26·683	8·929
666	25·807	8·733	713	26·702	8·934
667	25·826	8·737	714	26·721	8·938
668	25·846	8·742	715	26·739	8·942
669	25·865	8·746	716	26·758	8·946
670	25·884	8·75	717	26·777	8·95
671	25·904	8·755	718	26·796	8·955
672	25·923	8·759	719	26·814	8·959
673	25·942	8·763	720	26·833	8·963
674	25·962	8·768	721	26·851	8·967
675	25·981	8·772	722	26·87	8·971
676	26	8·776	723	26·889	8·975
677	26·019	8·781	724	26·907	8·979
678	26·038	8·785	725	26·926	8·984
679	26·058	8·789	726	26·944	8·988
680	26·077	8·794	727	26·963	8·992
681	26·096	8·798	728	26·981	8·996
682	26·115	8·802	729	27	9
683	26·134	8·807	730	27·019	9·004
684	26·153	8·811	731	27·037	9·008
685	26·173	8·815	732	27·055	9·012
686	26·192	8·819	733	27·074	9·016
687	26·211	8·824	734	27·092	9·021
688	26·23	8·828	735	27·111	9·025
689	26·249	8·832	736	27·129	9·029
690	26·268	8·837	737	27·148	9·033
691	26·287	8·841	738	27·166	9·037

No.	Square Root.	Cube Root.	No.	Square Root.	Cube Root.
739	27·185	9·041	786	28·036	9·229
740	27·203	9·045	787	28·054	9·233
741	27·221	9·049	788	28·071	9·238
742	27·24	9·053	789	28·089	9·24
743	27·258	9·057	790	28·107	9·244
744	27·276	9·061	791	28·125	9·248
745	27·295	9·065	792	28·142	9·252
746	27·313	9·069	793	28·16	9·256
747	27·331	9·073	794	28·178	9·26
748	27·35	9·078	795	28·196	9·264
749	27·368	9·082	796	28·213	9·268
750	27·386	9·086	797	28·231	9·272
751	27·404	9·09	798	28·249	9·275
752	27·423	9·094	799	28·267	9·279
753	27·441	9·098	800	28·284	9·283
754	27·459	9·102	801	28·302	9·287
755	27·477	9·106	802	28·32	9·291
756	27·495	9·11	803	28·337	9·295
757	27·514	9·114	804	28·355	9·299
758	27·532	9·118	805	28·373	9·302
759	27·55	9·122	806	28·39	9·306
760	27·568	9·126	807	28·408	9·31
761	27·586	9·13	808	28·425	9·314
762	27·604	9·134	809	28·443	9·318
763	27·622	9·138	810	28·46	9·322
764	27·641	9·142	811	28·478	9·326
765	27·659	9·146	812	28·496	9·329
766	27·677	9·15	813	28·513	9·333
767	27·695	9·154	814	28·531	9·337
768	27·713	9·158	815	28·548	9·341
769	27·731	9·162	816	28·566	9·345
770	27·749	9·166	817	28·583	9·348
771	27·767	9·17	818	28·601	9·352
772	27·785	9·174	819	28·618	9·356
773	27·803	9·178	820	28·636	9·36
774	27·821	9·182	821	28·653	9·364
775	27·839	9·185	822	28·671	9·368
776	27·857	9·189	823	28·688	9·371
777	27·875	9·193	824	28·705	9·375
778	27·893	9·197	825	28·723	9·379
779	27·911	9·201	826	28·74	9·383
780	27·928	9·205	827	28·758	9·386
781	27·946	9·209	828	28·775	9·39
782	27·964	9·213	829	28·792	9·394
783	27·982	9·217	830	28·81	9·398
784	28	9·221	831	28·827	9·402
785	28·018	9·925	832	28·844	9·405

No.	Square Root.	Cube Root.	No.	Square Root.	Cube Root.
833	28·862	9·409	880	29·665	9·583
834	28·879	9·413	881	29·682	9·586
835	28·896	9·417	882	29·698	9·59
836	28·914	9·42	883	29·715	9·594
837	28·931	9·424	884	29·732	9·597
838	28·948	9·428	885	29·749	9·601
839	28·965	9·432	886	29·766	9·605
840	28·983	9·435	887	29·783	9·608
841	29	9·439	888	29·799	9·612
842	29·017	9·443	889	29·816	9·615
843	29·034	9·447	890	29·833	9·619
844	29·052	9·45	891	29·85	9·623
845	29·069	9·454	892	29·866	9·626
846	29·086	9 458	893	29·883	9·63
847	29·103	9·462	894	29·9	9·633
848	29·12	9·465	895	29·917	9·637
849	29·138	9·469	896	29·933	9·641
850	29·155	9·473	897	29·95	9·644
851	29·172	9·476	898	29·967	9·648
852	29·189	9·48	899	29·983	9·651
853	29·206	9·484	900	30	9·655
854	29·223	9·488	901	30·017	9·658
855	29·24	9·491	902	30·033	9·662
856	29 257	9·495	903	30·05	9·666
857	29·275	9·499	904	30·067	9·669
858	29·292	9·502	905	30·083	9·673
859	29 309	9·506	906	30·1	9·676
860	29·326	9·51	907	30·116	9·68
861	29·343	9·513	908	30·133	9·683
862	29·36	9·517	909	30·15	9·687
863	29·377	9·521	910	30·163	9·691
864	29·394	9·524	911	30·183	9·694
865	29·411	9·528	912	30·199	9 698
866	29·428	9·532	913	30·216	9·701
867	29·445	9·535	914	30·232	9·705
868	29·462	9·539	915	30·249	9·708
869	29·479	9·543	916	30·265	9·712
870	29·496	9·546	917	30·282	9·715
871	29 513	9·55	918	30·299	9·719
872	29·530	9·554	919	30·315	9·722
873	29·547	9·557	920	30·332	9·726
874	29·563	9·561	921	30·348	9·729
875	29·58	9·565	922	30·364	9·733
876	29·597	9·568	923	30·381	9·736
877	29·614	9·572	924	30·397	9·74
878	29·631	9·576	925	30·414	9·743
879	29·648	9·579	926	30·43	9·747

No.	Square Root.	Cube Root.	No.	Square Root.	Cube Root.
927	30·447	9·75	964	31·048	9·879
928	30·463	9·754	965	31·064	9·882
929	30·48	9·758	966	31·081	9·885
930	30·496	9·761	967	31·097	9·889
931	30·512	9·764	968	31·113	9·892
932	30·529	9·768	969	31·129	9·896
933	30·545	9·771	970	31·145	9·899
934	30·561	9·775	971	31·161	9·902
935	30·578	9·778	972	31·177	9·906
936	30·594	9·783	973	31·193	9·909
937	30·61	9·785	974	31·209	9·913
938	30·627	9·789	975	31·225	9·916
939	30·643	9·792	976	31·241	9·919
940	30·659	9·796	977	31·257	9·923
941	30·676	9·799	978	31·273	9·926
942	30·692	9 803	979	31·289	9·93
943	30·708	9·806	980	31·305	9·933
944	30·725	9·81	981	31·321	9·936
945	30·741	9·813	982	31·337	9 94
946	30·757	9·817	983	31·353	9·943
947	30·773	9·820	984	31·369	9·946
948	30·79	9·824	985	31·385	9·95
949	30·806	9·827	986	31·401	9·953
950	30·822	9·83	987	31·417	9·956
951	30·838	9·834	988	31·432	9·96
952	30·854	8·837	989	31·448	9·963
953	30·871	9·841	990	31·464	9·967
954	30·887	9·844	991	31·48	9·97
955	30·903	9·848	992	31·496	9·973
956	30·919	9·851	993	31·512	9·977
957	30·935	9·855	994	31·528	9·98
958	30·952	9·858	995	31·544	9·983
959	30 968	9·861	996	31 559	9 987
960	30·984	9·865	997	31·575	9·99
961	31	9·868	998	31·591	9·993
962	31·016	9·872	999	31·607	9·997
963	31 032	9·875			

THE END.

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